



**Science
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The Machine in the Garden

The Advent of Industrial
Research Infrastructure
in the Academic Milieu

A Discussion Paper
by James B. MacAulay
in collaboration with
Paul Dufour

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March 1984

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FOREWORD

It is increasingly clear that well-developed and effective linkages between the academic and industrial sectors are important to strengthening the research infrastructure of industrialized nations. The debate surrounding the issue of industry-university interaction is not unique to Canada, nor is it recent. Many experiments have been conducted on ways of transferring knowledge and technology from one sector to the other.

In Canada, the public and private discussions on university-industry interactions are largely influenced by the experience of other countries. Indeed, several of our programs, policies and structures developed to stimulate linkages between the sectors have been modifications of these other, more established cases.

Quite often, however, this country's experimentation has been conducted in a vacuum, in ignorance of both the details of the Canadian situation and of the many models that exist elsewhere. Structural problems such as foreign ownership and the accompanying lack of industrial research have been cited as reasons for the weak ties between the academic and private sectors, but there are equally critical, institutional impediments that are historical and specific to the Canadian experience. They are the subject of this paper.

The Machine in the Garden: The Advent of Industrial Research Infrastructure in the Academic Milieu is an attempt to review the problems surrounding institutional linkages between industry and universities in Canada. It treats the historical marriage of science and technology and their separate institu-

tional embodiments in academic and industrial research. The paper documents the historical development of the university infrastructure and explores Canadian case studies of university-industry linkages. It describes the astounding array of government programs in support of university-industry interaction, identifies several factors that inhibit the interaction, and addresses the conditions for effective linkages between industry and academe. For those concerned about the potential damage to academic freedom through exposure to industrial linkages, a provocative discussion of this subject is included.

In offering this discussion paper as a significant contribution to the debate on university-industry interaction, the Science Council is adding to its other publications that touched on this issue. These include the Chairman's statement of 1981 on University-Industry Interaction; the proceedings of a workshop on the Challenge of the Research Complex; and Background Study 51 by Donald J. Le Roy and Paul Dufour, Partners in Industrial Strategy: The Special Role of the Provincial Research Organizations.

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The opinions expressed in this paper are those of its author and do not necessarily represent the views of the Science Council.

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PREFACE

The Machine in the Garden owes its title to literary and social critic Leo Marx, who, in his book The Machine in the Garden: Technology and the Pastoral Ideal in America (Oxford University Press, 1964), described the intrusion of the machinery of the industrial revolution into the romantic mental landscape of America. This study is concerned with the demands of industrial technology on our oldest knowledge institutions, the universities. Those demands have imposed themselves upon the university milieu in the form of a large number of new institutions, one of which is the research factory - a specialized facility for generating industrial technology in the quiet gardens of academe.

Much useful information for this paper was provided by the many individuals involved in building research institutions of the type described in this volume. In interviews, correspondence and formal meetings, these people took the time to tell me how such institutions are actually established. I am grateful to them all for their care and consideration.

James B. MacAulay



I INTRODUCTION

In this paper Paul Dufour and I investigate the processes through which universities have become related to the world of industrial technology. We have sought to isolate the principal issues surrounding this relationship and to describe the policy options available in Canada. In particular, we focus on the phenomenon known as institution-building.¹

Industry-university links have been poorly developed in Canada. The reason for this lies in a situation that has faced virtually all those - commissioners, councillors and senators - who have studied Canadian science policy over the past two decades: the inadequacies of industrial science and research.

In Canada slightly more than 1 per cent of gross national product (GNP) is accounted for by research and development in all sectors; of that, industry performs about 48 per cent. By contrast, the industrialized countries with which Canada must compete for export markets frequently allocate up to 2.5 per cent of GNP to research, and generally some 60 per cent to 70 per cent of that is performed by industry. Moreover, the industrial research capacity that does exist in Canada is concentrated among relatively few, often very large, firms.

There are those who have sought fundamental reasons for the insufficiency of research in Canadian industry. They have stressed structural factors such as the prevalence of small and medium-sized firms and of subsidiary firms under foreign ownership, and their dispersion in terms both of geography and market

economics.² However, international statistical comparisons and structural analysis may tell a misleading or incomplete story.

History makes a useful point. It is that the uneven sectoral nature of our research capacity is still unfolding. Science and technology grow not in a vacuum, but within a complex of support institutions, which include normative arrangements and support services as well as physical research facilities. This institutional complex provides those necessary conditions for research and growth in science that we call the research infrastructure. In Canada the infrastructure evolved first in the government sector in departments related to the resource economy. These provided an initial market for research-trained scientists and permitted the university sector to develop its research capacity at the periphery of the international science community.

The process of institution-building has now intensified in areas of industrial technology. Institution-building necessarily evolves from an existing base, and creating this base requires a good deal of concerted activity in institutional experiments that link current research capabilities in university and government with industry. Many barriers to such linkage exist, and many policy instruments have been devised to overcome them.

Perhaps the major barrier to the adoption of industrial research by universities is the idea that academic science must be somehow pure and above strictly utilitarian considerations. We could dismiss this as Victorian nonsense, but it cannot be ignored because it has been institutionalized in so many forms. The historical linkage of science and technology with the forms of institutionalization will be examined in the following chapters. We shall see that the machine (i.e., industrial research and technology) has long ago made its appearance in the quiet gardens of academe, without the devastating effects that have been feared.

II

THE MARRIAGE OF SCIENCE AND TECHNOLOGY

The myth that science is divorced from technology can be traced to the beginning of Western science. Classical scholarship suggests that two factors were critical to this uniquely Western phenomenon: a slave economy and a phonetic, arithmetic alphabet.

The classical world developed many different formal systems of natural philosophy at the same time as it produced remarkable technological achievements; yet in every respect it separated the study of the nature of things from the technical knowledge of how to do things. Scientific knowledge was developed by methods different from those used in the development of technical knowledge and machines; moreover, it developed in the hands of an entirely different class of people and was preserved in very different, very literate forms. The idea that the understanding of nature might be put to practical purpose just did not arise. Professor Cornford attributes this attitude to the social and economic conditions of the time; in particular, he draws attention to the widespread availability of slave labour:

It is estimated that when Pericles died, the population of Attica was divided into a little more than 200,000 freemen and 115,000 slaves. Abundant slave labour makes it unnecessary to enlist non-human force in industry. There was thus no economic pressure driving men to study Nature as a source of mechanical power.¹

This factor would not in itself be sufficient to explain the separation of scientific from other kinds of knowledge. For scientific knowledge to become

separated from its religious and mythopoeic past and made into an object of discursive thought, developments were also necessary in the language by which that thought was transmitted. The store of knowledge (sometimes called the tribal encyclopedia of the Greeks) was not richer or more original than its Egyptian and Assyrian antecedents. But towards the end of the fifth century BC, the Greeks began to separate the knowing speculating subject from this tribal encyclopedia and to make both the known and the process of knowing the objects of inquiry. How was this separation achieved? "The fundamental answer," says Professor Havelock, "must lie in the changing technology of communication."² According to this argument, then, at the birth of discursive science in its purest Platonic form, two imperfect and crude systems existed: a slave economy strong enough to support a secular leisure class and an alphabet of arithmetic and phonetic signs and syntactical rules by which existing knowledge could be recorded and subjected to analysis.

This classical form of individualism evolved a worldview of itself and its ideas as completely separate from the material world. That eminent Whig and master of the long sentence, Lord Macaulay, records the persistence of this pure science view as follows:

Once indeed Posidonius, a distinguished writer of the age of Cicero and Caesar, so far forgot himself as to enumerate, among the humbler blessings which mankind owed to philosophy, the discovery of the principle of the arch, and the introduction of the use of metals. This eulogy was considered as an affront, and was taken up with proper spirit. Seneca vehemently disclaims these insulting compliments. Philosophy, according to him, has nothing to do with teaching men to rear arched roofs over their heads. The true philosopher does not care whether he has an arched roof or any roof. Philosophy has nothing to do with teaching men the uses of metals. She teaches us to be independent of all material substances, of all mechanical contrivances.... "In my own time," says Seneca, "there have been inventions of this sort, transparent windows, tubes for diffusing warmth equally through all parts of a building, short-hand, which has been carried to such a perfection that a writer can keep pace with the

most rapid speaker. But the inventing of such things is drudgery for the lowest slaves; philosophy lies deeper. It is not her office to teach men how to use their hands. The object of her lessons is to form the soul. Non est, inquam, instrumentorum ad usus necessarios opifex."³

Although the Christian fathers somewhat abruptly reintegrated natural philosophy with theological ideas, this only served to strengthen the authority of the complete separation of scientific knowledge from the world of technology. The reintegration of science and technology took place only gradually through the late medieval and Renaissance period.

Historians have never experienced the difficulty in relating developments in technology to social and economic conditions that they have in relating science to its social milieu. There is still room for debate about the factors involved in the reformation of science in the Renaissance period. However, there can now be little doubt about the eventual outcome: the reunion of Western science with technology. But the partners in this union were themselves rapidly changing and were transformed in the process. We know that craft technology became an important source of instrumentation for science: Galileo's telescope and Boyle's air pumps are only the better known examples. But the most imposing developments in technology, for a society that was not slave-driven, involved the industrial development and control of power - often, of power-driven machinery. Here, the influence on science, though profound, was often very gradual, and differed from one science to another.

"... it may be naive to assume that even major technological advances suggested, contemporaneously, such questions worthy of scientific enquiry as would, indeed, immediately spring to our own minds. The scientific examination of the three useful forms of iron - cast iron, wrought iron, and steel - did not begin until the early eighteenth century; the geometrical theory of gear-wheels was initiated about fifty years earlier; the serious study of the chemistry of the ceramics industry was undertaken a little later. I choose deliberately examples of practical science each associated with notable developments in late-medieval craftsmanship: the intro-

duction, respectively, of the effective blast-furnace; of the gear-train in the windmill, water-mill, mechanical clock and other devices; and of fine, brightly pigmented, tin-glazed earthenware. The time lag in each instance between the establishment of a new craft-skill, and the effective appearance of scientific interest in it, is of the order of 250 years, and in each of these examples it appears after the scientific revolution was well underway."⁴

Industrial technology exhibited a growing ability effectively to control virtually any process that could be found in nature, isolated, and its components reduced to a functioning mechanism, and this also provided science with an important model. It was a model not just of how nature works, but of how the scientist might work as well. Thus, at a surface level, the marriage of science and technology can be thought of as placing craft instruments in the hands of scientists. At another level, it can be thought of as introducing into science investigative procedures that represented the talents and habits of thought and practice of engineers as well as of experimental scientists. The knowing subject of Greek science had become an intellectual entrepreneur, a commercially aware individual who published his knowledge claims in the vernacular press. But the machine made its appearance at an even more fundamental level: Galileo was adding some of the pieces to what eventually surfaced as a completed mechanical theory of the universe.

The commonly held view that technology is merely an application of science is not only simplistic and logically backwards but also quite inaccurate historically. A good discussion of the historical case may be found in Melvin Kranzberg,⁵ but it is also clear from the experience of major research projects since WW II that technology and science are frequently integrated and interdependent within the research process and in the system of knowledge that results.

If science and technology adopted and to some extent transformed each other, it was on a selective and imperfect basis. Usher⁶ had observed a full millenium separating the technology of the Egyptian balance from scien-

tific interest in it. Hall (note 6) cites several Renaissance examples where this period was narrowed to about one-quarter, or 250 years. The science-technology relation became much closer at all levels during the next large-scale revolution in industrial technology, when steam power was applied to machinery of all types. Here the ideals of utility and progress, as well as that of control, began to be realized, as if they were the marriage vows of the new union of science and technology.

Improvements to the steam engine had been made on a more or less continuous basis throughout the 18th century, and many patents were issued that reflected an increasing reliability and control through such devices as condensers and control valves.⁷ In 1811, Joel Lean began publishing a newsletter, The Engine Reporter, which routinely reported the results of efficiency readings on all engines operating in his county of Cornwall. This speeded up the rate of innovation; it also supplied engineering data directly into the scientific work of Sadi Carnot, separated now by only a few years from the underlying technology.⁸ Carnot's theory about the conditions for the maximum efficiency of heat engines founded the science of thermodynamics and led directly to the second law of thermodynamics. This work in turn formed the basis for the engineering of all heat engines, and although its effect on industrial technology cannot be doubted, it is typical of the problem of unravelling the relations of influence between basic research and technology that Carnot's work was left unread for many years. Indeed, it was left to Lord Kelvin to acknowledge the importance of Carnot a full generation later. Like so many fundamental contributions, his work was the necessary precondition of subsequent technical developments.

It is curious that as science and technology became more closely linked, their ideology diverged. Engineering came to be more and more highly organized as a profession and identifiable as an industrial career. At the same time science, in reality drawn further into industrial and military service, began to repudiate utilitarianism and adopt the isolation myths of classical times.

III

THE INSTITUTIONAL DEVELOPMENT OF SCIENCE AND TECHNOLOGY

Science and technology have become so interconnected and interdependent that, in many research areas, the old categories of homo sapiens and homo faber are frequently identified in one and the same investigator. Whether new knowledge turns out to be relevant to some industrial purpose or only to the further development of knowledge in the same area now depends on how and by whom it is used. Knowledge itself has inherently neither theoretical nor utilitarian properties. The motivations of an investigator become irrelevant to this point once a contribution has become public knowledge. Therefore, the difficulties of developing research on the frontier of industry and the university cannot simply be attributed to the assumption that science is one kind of knowledge and technology is another.

The fact is that science and technology became institutionalized in different forms and circumstances. In our investigation of the Canadian experience of university-industry links and the literature on the foreign experience, we noted many obstacles to effective collaboration. (These are discussed in the chapters that follow.) Without exception, they can be traced to a common fundamental dilemma: while science and technology have gradually been integrated, the institutions within which they have developed have very separate histories and are frequently at odds. We will not attempt a full account of the institutional history of technology; it will be sufficient to establish a few historical landmarks.

Institutions are mechanisms by which societies perpetuate their internal patterns of interaction, along with the values, knowledge and other resources

associated with those patterns. Institutions are therefore really coding devices, though most often the code itself has not been deliberately designed or even thought about as an object of inquiry.

We may isolate four levels in the analysis of institutions: (1) a set of physical resources or facilities such as may be found at any research institution; (2) an organization or structure by which participants interact and have behavioural expectations of each other; (3) a set of rules or norms that constrain possible behaviours; and (4) a set of goals, values or purposes that in varying degrees has been accepted by members. Change at any of these levels may influence the others.

We are concerned in this paper with knowledge institutions - mechanisms by which scientific and technical knowledge is generated, preserved and diffused. The university from medieval times has been such a knowledge institution, elaborately specifying the rights and duties of teaching masters and students, and operating within the constraining environment of other institutions of church and state.¹ Western knowledge institutions have always harboured a research function by which new knowledge is generated within the constraints of a scholarly community and apart from the authority of patrons. This activity characterized all our knowledge institutions from the Academy at Athens and the Library of Alexandria to the Cathedral School at Chartres and the University of Paris. Within those early knowledge institutions, there arose (and remains) an inevitable tension arising from the claims to authority over new knowledge: the claim of the knowledge community against that of institutions that patronize and support the community.

As natural philosophers of the late medieval period began to experiment with new instruments and methods and to derive new knowledge inconsistent with the conclusions of the past, the university was both the principal location of the effective institutionalization of existing knowledge and values and the home of the research community itself. It thus became necessary for a reformed science to evolve institutions outside the university.

The scientific societies that appeared in the 17th century explicitly sought to exclude the sources of controversy. As Robert Hooke put it in his draft of a "Plan for the Royal Society of London":

This Society will not own any hypothesis, system or doctrine... (not meddling with Divinity, Metaphysics, Moralls, Politicks, Grammar, Rhetorick, or Logick).²

Within these constraints - politically expedient constraints, given the crisis of politics and religion, and themselves subject to change - the knowledge community itself would evaluate and legitimize its understanding of nature. New knowledge would be submitted to the judgement of peers who, for the moment, were committed to the experimental method.

To achieve this, the community required more than a place to meet and discuss experiments. (In fact, although the Académie française provided a fully equipped national laboratory, for the most part scientists continued teaching in universities and using facilities that were not part of their new professional societies.) The most important institutional achievement of the societies was to devise a means whereby new knowledge could be circulated widely and evaluated.

Informal attempts had been made to circulate through private correspondence the results of investigations. Henry Oldenburg, corresponding secretary of the Royal Society, through a journal, The Philosophical Transactions of the Royal Society (published since 1665), created an institutional form of exchange for handling intellectual property. In this way an investigator might place his findings in the public domain in exchange for evaluation at the hands of his peers and public recognition of his priority of discovery. This ingenious mechanism remains central to the development of science; it does assume, however, that new scientific knowledge can be coded and diffused as a published paper.

Technological knowledge presents a very different problem. Comparable institutions to generate, preserve and diffuse technical knowledge could not easily develop for two main reasons: first, knowledge of processes and techniques tended to be learned and passed on in the form of skills and, to some extent, to be embedded in the machinery and industrial process itself; second, as noted, the somewhat rigid social stratification of science and engineering prevented mobility between the two activities. For both these reasons, technology remained the preserve of the working classes and craft guilds until well into the industrial revolution and did not easily become the subject of the processes of abstraction, speculation and experimentation or analysis that characterized inquiry in science.

From the late Medieval period on, industry progressed rapidly on the strength of innovations. Although technical papers were circulated as journals evolved,³ the exchange of intellectual property in technology was chiefly institutionalized in the system of patents. This took the form of a legal contract between the inventor and the state, whereby a monopoly was granted for commercial exploitation of the technology over a limited period, in exchange for disclosure in the form of a description of the invention or process and its application. These legal arrangements varied from one country to another - they were actually written into the US constitution - but always allowed for trade in the patent, through licensing or sale.⁴ Two effects are important for our purposes: the recurring tendency to disclose as little of the information as possible and a modern tendency for technology to concentrate within large firms. (It must be remembered that those who drafted the US constitution had no conception of a modern corporation.)

The institutional linkage of science and technology to the university eventually came about as each separately professionalized and required the university to perform its traditional role of teaching and recruitment for them as it did for other learned professions. With the reformation of German universities beginning about 1825, European science began to be organized along cosmopolitan, disciplinary lines, with well-established chairs carrying teaching and research functions. The value of research training was also

beginning to be recognized in industry; in Germany, particularly, the industrial demand for organic chemists began to push university science in the direction of more extensive applied and specialized research.⁵ The universities adapted to this situation, and in general they were independent enough to begin to respond to state and industry on an organization-client basis. Students had been the principal client-members of the medieval university, and central to its functioning, but students are only one of the several means by which the modern university transfers information to its corporate clientele.

For reasons already discussed, the same universities that easily adapted to the changing world of science were unable, and often unwilling, to incorporate industrial technology into their teaching and research activities. It was banished in Germany to technical colleges, and the French established a completely separate technical university, the *École polytechnique*. From 1851 on there were periodic industrial exhibitions, and competition in technology-intensive goods intensified. Public and government support for technological education resulted in applied science chairs at, for instance, Manchester and London. Nevertheless, at the beginning of this century, the institutional forms that embodied science research remained widely separated from those of technology. Investigators in traditional science had by then become professionalized and were beginning to find a home in the graduate schools and laboratories of a few universities; on the other hand, scientific and technical knowledge that was industrially relevant largely remained in the hands of the firm and its skilled craftsmen and engineers. The latter were also becoming professionalized, but were locally oriented to the goals of their own firms rather than to more cosmopolitan interests. The control of craftsmen over technical knowledge was passing to a new class of manager-engineers who were able, through the patent system, to contain developing technology at the level of the firm and exploit it to the firm's advantage.⁶

IV

THE EVOLVING RESEARCH INFRASTRUCTURE IN CANADA

In North America university colleges were established under religious and occasionally state patronage, usually following European models; and for a very long time, their preference was for European professors. When Canadian scientists appeared on the world stage (and increasingly through the 19th century, Canadian and American scientists did so), they offered peripheral contributions to research fronts located in the societies, journals and universities of Europe. This is consistent with the centre-periphery model wherein the development of research institutions on the frontier is entirely derivative and under the essentially colonial guidance of institutions in the European centres of research.¹

But this model is inadequate. It ignores the tremendous energy of American industrial technology, which outpaced that of Europe before the end of the century. It also ignores the Americans' individual and inventive approach to institution-building: for example, the development of doctoral research programs at Johns Hopkins in 1876, which were diffused throughout North America within a generation; and the establishment of Land Grant colleges after 1863, which linked agricultural and engineering faculties with their surrounding industrial base. This linkage, early established at Harvard and Yale by the endowments of Lawrence and Sheffield, was repeated in the technical universities founded on America's new industrial wealth.² Finally, the centre-periphery model ignores the American tradition of individualism and decentralization in science, which is evident in the establishment of engineering societies, journals and the specialized research facilities of industrial and consulting firms.³

Although Canadian science emerged from colonial dependency more slowly, Canadians violated the centre-periphery model in at least one significant respect - the use of state power in creating Crown research agencies, which were occasionally located at universities and often were relevant to industry. The Geological Survey of Canada was the first of these research agencies. It was founded in 1842 by the Province of Canada, then a colony embracing Ontario and Québec.⁴ The Survey was located on the campus of McGill University. Within 35 years the Survey and the university had developed what was probably the most important world centre for research in geology.⁵ After Confederation, the federal government removed this facility to Ottawa and reduced its independence, making it a division in the Department of Mines. Like the research facilities in other line departments, the Survey found it much more difficult to maintain its constructive relations with the mining industry on one side and the academic community on the other. Nevertheless, the Survey provided a model, subsequently used by federal and provincial governments, by which scientific and industrial purposes could be served by research institutions representing all sectors. In a note to a senior colleague in England, Sir William Logan identified this combination of motives:

From the fact that the survey has been urged by the Legislature of the country, it is natural to infer that a great desire is felt by the enlightened part of the Canadian community to be made acquainted with the leading geological features of the province; but the main object of the investigation is, no doubt, to determine the mineral riches of the colony.⁶

The Government of Canada continued this approach, establishing experimental farms (1886) and biological stations. The latter were eventually grouped under the Fisheries Research Board (1898). All of this was in place and enjoying considerable success before research capacity was established in the universities or (much later) in private industry.

As long as these government research institutions were operating in primary industrial areas (or later in areas such as atomic energy where an industry would be created around the government initiative), they were effective. The

expertise and knowledge they developed was a public good, raising the level of technology of whole industrial areas and sometimes making a new industry possible or viable. For example, once a resistant strain of cereal grain was developed or an orebody or sedimentary basin identified, it was only necessary to find an equitable and effective way to diffuse the information. Great problems were to be encountered, however, when this type of institution adapted to science in proprietary areas of industrial technology or entered traditional academic fields.

On the university side, the struggle to establish science and engineering departments began to have an effect in the last quarter of the century. As in Europe, a major barrier to establishing these departments was in sorting out the patronage and control arrangements between church and state. In 1841, the colonial government unsuccessfully tried to support the development of a common system of education and introduced legislation to this effect. The attempt did not prevail over competing demands from religion and culture, and in the British North America Act of 1867 provincial jurisdiction was established over education. This, of course, had far-reaching repercussions, but the immediate effect was to isolate university research capacity, which had to evolve locally and apart from the influence of central economic policy, taxing powers and institution-building capability. Provincial governments were initially forced into a brokerage role among competing religious and cultural interests, and institution-building in university science came to rely heavily on individuals and philanthropists at the local level.

McGill University was the most fertile ground for this kind of institution-building, having adopted a Scottish model for the university in which a utilitarian view of science figured prominently. The industrial wealth of the country was largely located in Montréal at that time; James McGill himself traded into that vast network of fur and timber interests based in Montréal that extended to Louisiana and the far North-West. The university never lost touch with its industrial clientele, which, in turn, under the guidance of Principal J.W. Dawson (1820-1899), provided not only generous patronage, but also an outlet for the graduates of the evolving science and engineering pro-

grams.⁷ Similarly, a School of Mining was initiated at Queen's University in 1893; at the University of Toronto, the School of Practical Science, established earlier by the provincial government, began offering degree courses in 1892.⁸

By the turn of the century science and technology were established in the curriculum, but organized research, as President Loudon of the Royal Society of Canada reported, could still "scarcely be said to exist" in the universities. He did, however, go on to call for an end to our scientific colonialism:

The time has surely come when we should cease to take all our knowledge at second hand from abroad, and when we should do some original thinking suitable to our own circumstances.⁹

Part of the mechanism for this was already at hand. Doctoral research training, pioneered at Johns Hopkins, was being adopted at McGill and Toronto. Support for the idea of the research degree spread rapidly. The other part of the mechanism came with the establishment in 1916 of the National Research Council (NRC), and though the NRC laboratory was not opened until 1932, its essential support for research students and projects in science began immediately. These two developments - adoption of American-style graduate research programs and the NRC - were the unintended but thoroughly rational response to a mounting colonial pressure, which was attempting to draw the scientific resources of universities throughout the British Empire more directly into the British sphere. At first, the mechanism for this pressure was the Allied Colonial Universities Conference; later, the Imperial War Cabinet presumed to communicate directly with colonial universities through its Department of Munitions.¹⁰

Meantime, provincial governments were becoming interested in linking the research and teaching capabilities of the universities in their jurisdiction to the requirements of industrial development. At the University of Toronto the "first regular Provincial grant authorized for the University since its founding" was provided for science programs related to the mineral wealth of

Ontario; this was followed by regular operating grants in support of chemistry, physics, mineralogy and geology on the basis of their potential contribution to the development of the province.¹¹ Perhaps the boldest move in this direction was taken by the Government of Alberta at a time when the extent of NRC development at the federal level was still very much undecided and the province itself was only 15 years old. Dr. H.M. Tory had established an industrial laboratory in the University of Alberta in 1911; in the immediate postwar period this became the basis of the Scientific and Industrial Research Council of Alberta, which was to link government and industrial interests in science.¹² (A case study of the Alberta complex is included below in chapter 6.) Members of the staff of the Research Council belonged to the Industrial Research Department of the university, and they were given support and independent authority to develop a research program, under an advisory committee drawn from all sides, in the general area of resource development.

It must not be assumed from this that Canadian universities were in fact reorienting themselves towards an industrial clientele. Tory was pre-eminent among institution-builders who understood the value of industrial links, but the universities he helped to create were on the McGill model, with significant influence from the University of Toronto and lesser influences from the state universities in Wisconsin and Ohio.¹³ He was not interested in a research factory, he did not favour religious influence in universities, and he fought control of professional schools by professional associations. Tory and others saw a secular incorporation of professional schools around a central core of traditional disciplines, with specialized graduate training and research capability. All this would be substantially supported by the state, under the external guidance of a board of governors and the internal self-government of a senate composed of senior professors and management. This view is important because it prevailed in Canada. The *École polytechnique* and the University of Waterloo were exceptions, modelled on the French and American experience, with a technical university built around a core engineering curriculum.¹⁴

There had been a gradual professionalization of technology and expertise in all areas, and the type of university that prevailed in Canada permitted

the relocation and establishment of the technical knowledge associated with professional practice in the academic milieu. Precisely this had of course been the accomplishment of medieval universities in medicine and law; and the value in teaching and research of clinical affiliations can hardly be overstated. But the extension of university-based professional training into many key areas of industrial technology represents an interim step whereby the university could accumulate much valuable experience, through cooperative programs and professional accreditation committees and the like, in dealing from a position of authority with their industrial clientele. Still it is only an interim step because, as we shall see, effective research activities in these areas of industrial relevance require more than the facilities for professional education.

State support of the universities, though crucial, was available on the crude basis of numbers of students. Thus, in the absence of non-government funds (often available in medicine), universities with research capacity in the form of faculty were forced to fund it through student numbers (often thinly disguised as "income units"). When a formula was found for injecting substantial federal revenues into the university system, it was through the same provincial mechanism. Thus the federal money, far from placing resources in the hands of those who might create new research institutions, simply had the effect, particularly in the 1960s, of keeping rapidly expanding universities solvent. At each campus the budgetary process was essentially one of negotiation among departments and schools. The tendency was for funds to flow to the departments that generated income through student numbers, and this constrained development of new research capacity. As a result, each university had a tendency to create essentially the same research capability as all the others.

There remained limited degrees of freedom. A tradition of endowed chairs, industrial scholarships and direct philanthropy had survived at McGill and Toronto particularly. In the following chapter we shall examine the support, especially of research, that the industrial linkage has contributed. The story

of the unfolding research infrastructure is incomplete, however, without returning to the Crown agency instrument.

In their survey¹⁵ Arthur Cordell and James Gilmour observed that the research facilities of the federal government have no orientation to industry. The laboratories of government departments frequently were set up only to perform science related to regulatory functions and to feed technical information into departmental programs. The laboratories were concentrated in Ottawa, whereas monitoring and testing activities tended to be relegated to regional laboratories. Such constraints on the evolution of a research base in government were at least as smothering as those in the universities. But in the face of these dismal prospects, federal and provincial governments have frequently permitted some freedom through the creation of Crown agencies, usually preceded by Royal Commissions.

One of the most independent of these was the Bank of Canada. The 1930s also saw the creation of a number of independent agencies such as marketing boards and the Canadian Broadcasting Corporation, which, according to its architect, Graham Spry, was to be "more like a university than a government agency."¹⁶ This time-honoured instrument of nation-building, the independent Crown agency, reappeared frequently in wartime as well. The National Research Council (NRC), emerging as a child of circumstances in World War I with a program of research support and little else, became such an instrument in 1924 when a revised act gave it arm's-length status and a new president, H.M. Tory. With university research evolving slowly through its teaching function, and with industrial research in its infancy even in the largest companies, Tory saw clearly the potential for a government agency along the lines of the fledgling Alberta Research Council, free of departmental rivalries yet substantial enough to deal primarily and effectively with industrial problems.¹⁷ The Canadian Manufacturers' Association (CMA) was exerting pressure in Toronto and Ottawa to establish industrial research facilities in an Ontario Research Foundation (ORF) as well as at the NRC. From the CMA's point of view, private laboratories or those established by trade associations such as the Pulp and Paper Research Institute (PAPRICAN) at McGill (see section on Industrial Research

Associations below) were not feasible for the bulk of their membership, composed chiefly of smaller manufacturing concerns.¹⁸

V

POLICY INSTRUMENTS

As these federal and provincial initiatives became established, many new instruments for university-industry linkages became possible. In this chapter we review the present range of policy instruments available to federal and provincial governments and the universities themselves.

Federal Policy Instruments

In every industrialized country, a range of policy instruments stimulates research and technology development in industry and supports research in universities. These programs are normally developed and administered by different government departments with very little collaboration. Canadian efforts are additionally compartmental because higher education and economic policy are constitutionally split between provincial and federal jurisdictions; at the same time, both levels of government assume responsibility for industrial and manpower development and research policy.

Central Agencies

Under the combined influence of the Rowell-Sirois Commission (1937-1940), the Massey Commission (1949-1951), the Association of Universities and Colleges of Canada (AUCC) and the pressure of postwar enrolments, a complex series of fiscal transfers from the federal to provincial treasuries has been negotiated and renegotiated since 1951-52. In 1981-82, under the Established Programs Financing Act, some \$19 billion in cash and tax transfers went out to the provinces in support of health and higher education. The proportion varied from one province to another but, on average, about 32 per cent was allocated to the support of higher education.¹ Efforts have been made from time to

time to rationalize the Established Programs Financing expenditures on higher education, and (with more success) to establish control machinery in the Council of Education Ministers; but the expenditures remain essentially beyond the immediate and effective control of any policy-making agency.² This funding is the principal means by which research capacity has been created in the universities, but the mechanism cannot yet be considered an effective policy instrument.

Federal departments and agencies have in place many programs to support science in university and in industry and a few to assist in collaborative or transfer activities. The struggle to coordinate and possibly to control these programs is really the history of science policy machinery in Ottawa. Perhaps Canada came closest to central coordination during wartime and immediately afterward with the NRC of C.J. Mackenzie, which combined in one agency rather extensive laboratory activities, university research support, industrial support, and Cabinet advisory functions. Although Canada clearly has never devised a coherent policy for science, through many Royal Commissions it has certainly established a policy for the rationalization of government machinery. This policy is one of functional differentiation - separate agencies are routinely created to perform discrete functions.

This policy was not effective to deal with science across the university-industry frontier, which involves all three sectors and both levels of government. More recent efforts have therefore been directed towards central agency control. Two examples deserve mention. First, as a result of the 1963 recommendations of the Glassco Royal Commission on Government Organization, the Treasury Board was split off from the Department of Finance and given the job of justifying expenditures, as well as accounting for them and attempting to control them. The Ministry of State for Science and Technology (MOSST), without line department functions in science, was able to develop a separate, advance statement of science estimates in all departments (the "Science Addendum"). On the two occasions the same person held simultaneously the portfolios of MOSST and the Treasury Board (as did C.M. Drury and Donald Johnston), MOSST was able to assist in the Cabinet level attempts at coordination of

science policies. Second, as a result of the Auditor General's Report for 1976 and the Lambert Commission on Financial Management and Accountability (1979), the office of the Comptroller General has evolved out of the Treasury Board with responsibilities in policy evaluation as well as coordination. For science expenditures, however, evaluation is still nominally in the hands of the originating departments.

On the coordination side, considerable progress has been made. A system of budgetary envelopes was adopted in 1979 that grouped the entire government expenditure into five areas, each with a budgetary ceiling and a controlling Cabinet committee. With the exception of medical research and health sciences, which were placed in the social affairs envelope (along with fiscal transfers for higher education - the Established Programs), the agencies and departments involved with science and industrial and regional development were placed in the economic development envelope. At the same time the budgetary cycle was rationalized and the envelopes placed under five committees of Cabinet. Thus, at the highest level policies for science, technology and economic development, as well as policy for energy, came under the budgetary control of the Cabinet's Economic and Regional Development Committee,³ the chairman of which also at present holds the MOSST portfolio.

The full implications of these changes have not been worked out as yet, but one effect will be that the arsenal of science policy instruments, some of which we consider below, can now be coordinated and to some extent brought under control and promoted in the appropriate policy arena. For example, the cost of changes in tax incentives for industrial research or technology development would now be met from the resources available to all programs in the economic development envelope. Thus the pros and cons of policy options can be debated at the appropriate level, and details of successful trisectoral experience in technology (in, for example, the Department of Communications) can begin to inform some of the other programs that frequently stall at the development stage.

National Research Council

Associate Committees: The problem orientation and immediacy of industrial research often present difficulties for investigators in traditional university departments or the laboratories of government departments. Some degree of freedom was needed; NRC, with its separate resource base and credibility in all sectors, was able to form Associate Committees to identify and initiate research programs in areas of promise. The Associate Committee can function like a Royal Commission inasmuch as it can co-opt all sides to a major undertaking. It may, to a professor interested in some industrial area obscure to his colleagues, function like the invention of a journal in a field that hitherto had no means of communication or exchange, and no laboratory facilities.

When a main problem arises the Council calls a conference of all the leading persons in Canada who are working on that problem or who are particularly qualified to advise concerning it, by reason of their special training or experience.⁴

Eggleston continues:

In a typical year there were estimated to be more than two hundred of the more eminent scientists and engineers in Canada serving without fee for such committees.⁵

The Associate Committee is a flexible instrument that can quickly mobilize research talent and support in areas that might cross departmental and disciplinary lines or federal-provincial jurisdictions, and almost certainly will involve all three sectors. Many of the industrial success stories at NRC were initiated in this way; in the following chapter, we examine one that led to the founding of the Prairie Regional Laboratory, and subsequent contributions to agriculture. At present there are some two dozen of these committees in areas ranging from space research to consulting engineering and technology transfer.⁶

IRAP and PILP: The Industrial Research Assistance Program (IRAP) has evolved from an industrial granting program in 1962 into a means for channelling NRC expertise to appropriate firms. IRAP now underwrites 40 per cent to 50 per cent of the manpower and equipment costs of approved industrial research projects. University as well as government scientists may be contracted into a project; consortiums of companies are sometimes involved. Intellectual property is completely protected in advance and the company may patent the results. Original contributions to an invention by government scientists are protected by the Public Service Inventions Act as well. A committee with considerable experience in industrial technology and marketing innovations evaluates incoming proposals.

Several specific elements are separated in the IRAP scheme. IRAP-L was designed specifically for smaller firms with little or no research capacity. It frequently works in tandem with IRAP-F (formerly the Technical Information Service, TIS). IRAP-F is already decentralized and maintains an ongoing consulting relationship with smaller manufacturing firms. It has 16 field offices, several of them located within the Provincial Research Organizations, and many on university campuses. Thus a network of professional-client relations has been built up. On this basis, IRAP-L (the use of government labs for testing an idea) and IRAP-M projects may often be developed in complementary fashion. A type of co-op program is now under development whereby an IRAP-H grant will support science and engineering undergraduates, under supervision, in an industrial firm. Some \$1.7 million was set aside for this element in 1982-83, with 357 projects funded in all provinces. IRAP has thus become flexible enough to act as a linkage instrument, though its main purpose is to put innovations in the marketplace, often where major industrial development costs are involved.

The other major industrial liaison program at NRC is PILP (Program for Industry/Laboratory Projects), initiated in 1975. Although university and Provincial Research Organization involvement in this program is planned, it is essentially an attempt at technology transfer from NRC laboratories and, more recently, from other government laboratories. Under PILP, firms contract to

develop marketable products and processes initiated in government laboratories. Again, contributions of government scientists are protected, and the contracting firm generally licenses the technology through Canadian Patents and Development Limited. PILP had 111 projects underway in 1982, involving a commitment of \$57 million of public funds.

NRC also developed three specific programs to link university research to industry, as well as an extensive system of research and equipment grants and scholarships in science and engineering. The programs, which directly involved universities, were developed and administered through the Committee on Grants and Scholarships (this division of the NRC was separated and became the Natural Sciences and Engineering Council (NSERC) in 1978). These programs became the chief means by which the Canadian professoriate was transformed into a research community. Also NRC laboratories had provided the first market for the research-trained graduates of Canadian universities. In 1960 the Medical Council of Canada was formed to administer most of the health-related granting functions of the NRC. The separation of NSERC and its taking over of university programs while NRC retained the laboratories and the industrial programs had negative effects on university-industry linkage activities.⁷ The difficulties this arrangement would impose on nascent programs are obvious and, as we shall see, have slowed down the necessary institution-building activity, which NRC has now resumed.

Regional Centres: In the Mackenzie period, NRC established two major regional laboratories: the Prairie Regional Laboratory (PRL) in Saskatoon in the 1940s (officially established in 1948, but actually functioning earlier) and the Atlantic Regional Laboratory in Dartmouth in 1952. Both these developments required a good deal of organizational innovation. PRL in particular has had considerable involvement with university and industry. PRL (recently renamed the Institute for Plant Biotechnology) is a vital part of the university-industry research complex at the University of Saskatchewan; we examine it in greater detail in the following chapter.

Building on this experience of university and industrial involvement, and also on the experience gained through IRAP and PILP of industrial projects in the development and demonstration phase, NRC in 1978 began again to experiment with regional centres. As before, there were political considerations in the location decisions, but the new laboratories are more independent of Ottawa, more directly involved in industrial technology and more dependent on the industrial and university partnership. Finally, they are part of a class of institution-building that deals directly with one of the greatest barriers to university-industry collaboration: that is, the non-university character of pilot plant and demonstration facilities in industrial research and technology. (These factors will be examined more carefully in the following chapters.) Two of the new regional centres are now established: the Industrial Materials Research Institute near Montréal, and the Arctic Vessel and Marine Research Institute at St. John's. The latter is located on the Memorial University campus (we shall examine it more closely as well in the following chapters). Regional laboratories for New Brunswick and Alberta are planned: a \$61 million biotechnology centre for Montréal and a \$41 million Institute for Manufacturing Technology for Winnipeg have recently been announced.

Natural Sciences and Engineering Research Council (NSERC)

Following a recommendation of the Macdonald Committee, the Grants and Scholarships Division was separated from NRC in May 1978 to form NSERC as a separate agency. The form of the government grant-in-aid for research goes back to 1849, when the Royal Society of London began to administer British Treasury funds for research. At that time the peer evaluation system was already well established for the publication of papers, and the system of direct grants was built up as an extension of peer evaluation. Funds were allocated as grants to individuals by other investigators in the research community, either as a reward or to defray the costs of experiments. The possibilities for intervening in a policy sense were thus essentially limited to the way the administering agency selected its peer evaluation committees.

Given provincial jurisdiction of universities in Canada, all these normative arrangements for evaluation, which go to the heart of the traditional

academic view of science as a self-governing republic, also complicated the task of NRC in its efforts to create a research community. As late as 1945:

Advanced students in Canada have only three English-speaking universities (Toronto, McGill and Queen's) which seriously attempt to provide staff and facilities for conclusive graduate work, that is, to the doctoral level, and these do so only in some areas. Canada does not possess a single fully-rounded graduate school. The result has been a steady movement south....⁸

NRC research grants and scholarships were thus part of a larger package of policy initiatives. In particular, the major equipment and core grants, the support of learned journals, negotiated development grants, operating grants for the support of groups and so forth were all instruments to aid development of an essential research infrastructure.

These policy initiatives included some effort to use the peer evaluation machinery to support university investigators interested in industrial problems. However, they were part of a package that, as noted above, included more ambitious institution-building activities in industrial technology outside the peer-review system. Therefore, the action of splitting away the peer-reviewed support to university from all the related activities that involved NRC in the construction of a research infrastructure obviously entails some considerable costs - costs that are most in evidence on the university-industry frontier.

Again, the notion that NSERC might develop a research policy at all is controversial; the Macdonald commission specifically excluded an active role for the granting councils, seeing NSERC in a passive role, responding to proposals from university investigators and administering awards made by committees of their colleagues. The Science Council rejected this advice; it felt granting councils should give "... broad guidance to the direction to be taken by university research.... We do not believe that the sum of the policies

of individual university researchers necessarily provides the best policy for the nation." The Council went on:

There is a need in Canada to achieve more coordination and a closer cooperation between the sectors of universities, government and industry. Within the university sector itself, it will be increasingly necessary to specialize and to concentrate efforts in order to achieve the standards of excellence we desire."⁹

These aspirations are indeed controversial, as the Ontario Ministry of Education has found (although there are good reasons for students to resist specialization of campuses with respect to the undergraduate curriculum), but in terms of research capacity they are rational and necessary. For NSERC to make a contribution to the rationalization of university research it will have to look beyond its strategic and operating grants and other schemes for individual support that unfortunately still constitute the bulk of its university-industry initiative.*

Industrial Research and Senior Industrial Fellowships: The Industrial Research Fellowship (IRF) scheme appeared in 1980-81 (replacing a former program) when it was found that in its ten years of operation the Industrial Postdoctoral Fellowship (IPDF) scheme had not achieved great success. There were in 1980 some 12,100 natural scientists and engineers engaged in research and development in industry; only 121 of them held IPDFs at that time, and in the whole period only 224 had been placed in industry under this program.¹⁰ The IRF is essentially the same program with a slightly higher stipend and longer period: it provides just under \$25,000 annually towards the salary of approved fellows over three years in an industrial research position, and \$10,000 for two succeeding years. In 1980-81, 26 awards were made; this has increased to 132 in 1982-83. Current expenditures are \$1.8 million.¹¹

* One indication that NSERC is moving in this direction is its recent announcement (25 January 1984) of measures to strengthen existing interface programs and to create new ones.

Senior Industrial Fellowships (SIF) are available to faculty members to spend one year in industry or quasi-industrial federal or provincial agencies. There is potential here for a multiplier effect on research in industry; small networks of relationships form, students move into industry and contracts follow between the university and industrial laboratories. But the SIF works on the initiative of individual faculty. The application rate has been disappointing - only 71 awards were made from 1971 to 1981. Nine fellowships were awarded in 1982-83, amounting to \$107,000. The program does nothing to ease the situation resulting from pressure to publish rather than perish in universities. Thus the professor, besides having to overcome the difficulty of finding a host industrial laboratory, may have to sacrifice his sabbatical year in this program rather than spend it in some form of academic research.

Project Research Applicable in Industry (PRAI): PRAI grants were initiated as Special Project grants in 1970. They were an attempt to identify industrially promising projects in universities and to support the demonstration phase of an R&D project, so that a relevant industrial firm might judge its commercial feasibility and somehow assist in its successful transfer to industry. The procedure resembles that for any operating grant, with the exception that over the years more industrial people have been added to the review committee. The funding decision is made on a proposal from a university investigator who has completed his research in the usual university sense and who has also found a company with which to collaborate in the demonstration. Several difficulties may arise: it is assumed that the investigator will have worked out some arrangement for intellectual property on his own; the host company cannot have exclusive patent rights; and finally, special equipment is supposed to already exist in the host firm. The program, like the SIF program described in the previous paragraph, is supposed to work on the initiative of individual faculty.

Not surprisingly, the PRAI program has never involved a large number of projects. The best year for applications was 1973, when 80 were received and about \$1.2 million awarded. The amount, even in current dollars, declined radically after that until the program was restructured; the expenditure level

in 1981-82 rose again to \$1.86 million (current dollars). After seven years, only two patents had resulted from 92 awards totalling \$5.5 million. The period of support has now been extended from two years to five, a gesture of realism introduced by the new Advisory Committee on Industry-University Interface at NSERC (recently reconstituted as the Task Force on University-Industry Interface).

The Indirect Method: We have noted that NSERC has experienced great difficulty in effectively supporting the development of industrial science and technology through programs for university science. This must be seen as a serious policy gap at the federal level, as NSERC is now the only federal agency with a specific mandate to fund university research in the physical sciences and engineering. Probably the Council's greatest impact on university-industry relations, and through them on industrial technology, is not through its linkage programs at all, but through its graduates. If we go back to the traditional model of the university as a client-serving institution with its industrial clients held at arm's length, a very different picture of NSERC emerges. The science and engineering graduates available to industry a generation ago could have had very little research training of any kind, quite apart from their lack of industrial sophistication. In the transformation of science faculties into a research community - and the grants and scholarships programs of NRC and NSERC were clearly critical to this - research-trained graduates have been an effective indirect means of influencing industrial science and technology.

Indeed, NSERC enriches the university-industry linkage indirectly not only by finding and supporting the best investigators doing science for its own sake, but also by using the traditional peer review machinery to develop research activities in engineering and targeted research on applied problems. The Council has had little success with the use of traditional panels to stimulate engineering research,¹² although NSERC panels, when considering research awards, now recognize patents and technical papers and, as mentioned, include more industrial people than before. Their experience with targeted research is somewhat more encouraging. Professors and students have responded

to a rapidly increasing budget for research in a number of targeted areas. These now include energy, environmental toxicology, oceans and ocean engineering, food and agriculture, communications, biotechnology (added in 1982-83) and other applied areas. The budget for this in 1982-83 was about \$26.3 million, and was expected to increase in relation to other areas.

There has also been a favourable response to research contracting from government departments. In times of inflation and restraint, in which real support per investigator has diminished, targeted and contract research became popular. As long as the applied nature of the research causes no problem in the evaluation and reward institutions of academic science, publications can be expected to emerge from these investigations, along with new professional associations and journals that declare the relevance of the work to the rest of knowledge as well as to social concerns. The key to the relevance of this research to industrial requirements, beyond the provision of qualified graduates, would be significant levels of new contracting from industrial sources. That, as we shall see, has not been forthcoming except in some special cases that we shall examine.

Department of Regional Industrial Expansion (DRIE)

The major institutions linking research activities in university and industry were initiated by NRC and the Department of Industry, Trade and Commerce (IT&C). The IT&C programs, along with Canadian Patents and Development Limited (CPDL) and several other agencies, have been grouped with the regional industrial programs under a new ministry, Department of Regional Industrial Expansion (DRIE). This ministry brings into one portfolio a considerable experience in industrial technology, including innovation, patenting and marketing, along with several large-scale regional projects for economic development. Not all these offer immediate possibilities for university researchers. In this section, therefore, we shall consider the established programs of IT&C that have brought about collaboration between university and industry.

Industrial Research Institutes (IRI): By 1967, many universities had built up a network of industrial relationships through contract research by the faculty and cooperative programs for student industrial experience. Also by that time, many universities had developed research administration offices, usually at the vice-presidential level, to cope with the paperwork entailed by research grants and contracts. Discussions between IT&C and several universities resulted in a new type of brokerage institution at the university-industry interface, the Industrial Research Institute.

The new brokerage institute would, first, more aggressively market the university's research expertise and facilities to its evolving network of industrial firms. Second, it would charge overhead costs and program management contracts, using the funds thus generated to become a self-supporting institution able to move information and influence in both directions across the interface.

Four of these institutes were established in 1967 at the Universities of Waterloo and Windsor, McMaster University and Nova Scotia Technical University. The Waterloo Research Institute, with an IT&C grant of \$244,557 over six years, became self-supporting in 1973; it gained expertise in the industrial evaluation of potential projects and in patents and licensing in the area of marketing. An Inventors' Assistance Program was also established, with the involvement of CPDL, along the lines of a similar program at Massachusetts Institute of Technology (MIT). Waterloo is the most successful of the 11 institutes (see Table 1) supported under the program, perhaps because Waterloo is the Canadian university most resembling an American technical university.

The other three institutes established in 1967 similarly became self-supporting in 1974, with the highest startup grant of \$358,000 going to the McMaster Centre for Applied Research and Engineering Design. (The McMaster Centre, in what was perhaps a regressive move, was later combined with the Office of Research Services.) In a detailed study of ten institutes, Sidney Featherman¹³ found success or failure to depend on such factors as interest and participation of academic staff, support from the university administra-

tion, a critical mass of local industrial clientele, established credibility with this clientele and the entrepreneurial acumen of directors of the institute.

Table 1: Industrial Research Institutes

Institution	Grant	Term	Grant Termination
1. Nova Scotia Tech.	\$270,000	7 years	March 31/74
2. Windsor	\$236,895	7 years	June 30/74
3. McMaster	\$358,000	7 years	Sept. 30/74
4. Waterloo	\$244,557	6 years	Nov. 30/73
5. Ryerson	\$150,000	5 years	July 31/77
6. Manitoba	\$405,000	7 years	Sept. 30/80
7. McGill	\$204,000	4 years	Aug. 15/75
8. École polytechnique	\$260,000	5 years	Sept. 30/76
9. U. du Québec à Mtl.	\$420,000	7 years	May 31/80
10. Guelph	\$150,000	3 years	March 31/76
11. U. of Ottawa	\$180,000	3 years	Dec. 31/83

Two of the institutes (Guelph and Ryerson) Featherman found to have failed. The others had varying degrees of success. The Office of Industrial Research at McGill University and the Centre de développement technologique of École polytechnique de Montréal run as smoothly as Waterloo.¹⁴ University size and location, number of research staff and availability of specialized research facilities and equipment are important additional reasons for success, as is the structure of such an institute, which usually takes the form of a small administrative office operating under the guidance of a governing or advisory board that includes local industrial people as well as university representatives. The fees charged are intended to cover the direct cost of contracted work as well as all indirect costs of university services provided.

While not precluding the establishment of more institutes, IT&C has wisely observed that a brokerage operation of this type is most effective where a network of university-industry relations already exists.

Centres of Advanced Technology (CAT): In 1970, IT&C began sponsoring a program that would involve universities more directly with industrial technology and management, using the universities' teaching resources, and moving towards centres of expertise in particular technologies. Its objectives were:

- (1) to provide assistance to industry in the form of basic and applied research;
- (2) to provide technical development assistance to industry;
- (3) to provide training for industrial personnel in specialized techniques of management, operation and evaluation of manufacturing facilities;
- (4) to provide training relevant to industrial needs to graduate and undergraduate students;
- (5) to promote research relevant to industrial needs by graduate students and the university.

Funded at a maximum rate of \$200,000 per year for up to seven years, 15 CATs have been established to date, as shown in Table 2. Because of the specific technological focus of each of these centres, their success or failure is dependent on resources of the centres themselves, including their administrators' motivation and initiative, particularly their marketing push, rather than on the overall resources of the parent institution. Financial viability among the CATs is a precarious thing.

Again, four of them, including the Systems Building Centre at the University of Toronto and the Centre de technologie de l'environnement à l'Université de Sherbrooke, have effectively failed. The centre at the University of Toronto apparently began with an incorrect appreciation of

demand from private industry and consequently was unable to obtain sufficient contracts.

Featherman has identified other difficulties in his evaluation of CAT performance. One of these is the host university's support. There is apparently no consistency in the rates for overhead charged to the centres, and several universities charge heavy rates in the initial years of a CAT's operation, making it very difficult for it to become self-financing.¹⁵ The report cites other reasons why reaching self-sufficiency may be more difficult for a CAT than for an Industrial Research Institute.

1. A CAT starts from scratch with its own small staff, whereas an IRI usually draws upon the university's faculty and its existing contacts with industry;
2. A CAT will often be involved with new technology that industry may be reluctant to adopt, and that requires a lengthy introductory period. IRIs, on the other hand, will generally do more conventional work;
3. The CAT will tend to specialize with respect to industrial clientele, and thus is sensitive to depressions in that sector of the economy. IRIs have greater flexibility and can contract from a number of sectors, thus avoiding specific weaknesses;
4. CATs are often involved in developmental work calling for large initial cash outflows; moreover, the time span required for recovery of money through royalties may be considerable.

The CAT type of institution calls for the acceptance of risk and entrepreneurship, just as new companies do - an area in which university administrators may have little experience and insufficient budget. The startup funds provided by IT&C are not enough for the establishment of new facilities and equipment, nor for the centre to exist for long without substantial industrial support. It is not surprising, therefore, that several of the more successful centres have Provincial Research Organizations as parent institutions. These are usually located at universities, but frequently already have facilities for specialized industrial technology,

technical information services and active industrial networks.¹⁶ For the others, it would have been useful had the NSERC Task Force on Research Equipment¹⁷ proposed placing specialized equipment centres in the established locations of these Centres of Advanced Technology, along with industrial demonstration and pilot plant equipment. The Task Force did not, however, exclude the possibility of such a development in future NSERC programs.

University Microelectronics Centres (UMC): Originally the federal government plan was for three microelectronics development centres in Canada, funded at \$2 million each. In June 1981, Herb Gray, Minister of IT&C, announced new plans for six centres, with the support level cut to \$1 million over five years. These centres were to be in BC, Alberta, Manitoba, Ontario, Québec, and a Maritime province, probably New Brunswick. Subsequently, in January 1982, IT&C bowed to pressures and agreed to fund "up to ten" institutes, one per province, at the rate of \$1 million over five years. All applications have now been received.¹⁸

Each centre is to be a non-profit corporation, operating in the same way as a Centre of Advanced Technology. UMCs will assist all sectors of the Canadian manufacturing and processing industry in the application of microelectronics to products and processes to become more competitive in domestic and foreign markets. The centres are intended for development, not research; that is, each UMC will develop applications for industry in its own region.

The centres are to be located near universities. Each will have a board of directors with representatives from regional sources of electronic and other industries, the universities and colleges, the general business community and the relevant departments and agencies of the federal and provincial governments. Directors from universities and colleges will not constitute a majority on any of the boards.¹⁹

Each centre will:

- (i) provide consulting service to industry in identifying applications of microelectronics;
- (ii) serve as a regional focal point for dissemination of information on microelectronics and its applications;
- (iii) provide technical assistance to industry in development projects concerning the application of microelectronics to products and processes;
- (iv) provide industrial training programs in these applications;
- (v) provide facilities at which regional industry can develop or participate in development projects involving those applications;
- (vi) promote the transfer of microelectronics technology to industry.

The centres are to become self-supporting through contracts to industry once the initial seed money is used up. They constitute part of a larger microelectronics support program undertaken by the federal government: a special electronics fund of \$50 million was originally announced in April 1980, with \$29 million originally allocated for major projects in proven firms.²⁰ Additional support announced in January 1982 raised to \$93 million the total funding level, of which \$10 million will be allocated to the UMCs, \$2.7 million for a countrywide industrial awareness and education program and the remainder to be divided between proven firms for major projects and a general industry incentive program known as STEP (Support for Technology Enhanced Productivity). This last, a three-part funding program to encourage manufacturing firms to incorporate microelectronics devices into products or operations, complements the development centres' services.

The first seven centres have begun functioning - five at the Universities of British Columbia, Alberta, Manitoba, Toronto, and Sherbrooke, and two shared between more than one institution. (In Nova Scotia the Technical University of Nova Scotia, Dalhousie University and the Nova Scotia Research Foundation Corporation share a centre; in New Brunswick a bilingual centre is shared between the University of New Brunswick [UNB] and Université de Moncton.) The Manitoba and Québec centres were already in operation before IT&C announced this recognition and support. Proposals for centres at the

Table 2: Centres of Advanced Technology and Parent Institutions

Centre	Grant & Term	Termination
1. Centre for Powder Metallurgy, Ontario Research Foundation	\$ 450,000 - 3 years	June 30/74
2. Systems Building Centre, University of Toronto	\$ 300,000 - 3 years	Sept. 30/74
3. Canadian Institute of Metalworking, McMaster University	\$ 830,000 - 6 years	Sept. 30/76
4. Centre for Ocean Engineering, BC Research	\$1,225,000 - 3 years	March 14/76
5. Centre de technologie de l'environnement, Université de Sherbrooke	\$ 300,000 - 3 years	Oct. 31/77
6. Centre for Ocean Technology, Nova Scotia Research Foundation Corporation	\$1,075,000 - 7 years	May 31/81
7. Systems Analysis, Control and Design Activity, University of Western Ontario	\$1,195,000 - 7 years	Oct. 31/80
8. Biomedical Instrumentation Develop- ment Unit, University of Toronto	\$ 875,000 - 5 years	Feb. 28/81
9. Canadian Food Products Development Centre, Manitoba Research Council	\$ 55,000 - 5 years	March 31/79
10. Health Industry Development Centre, Manitoba Research Council	\$225,000 - 3 years	Dec. 31/79
11. Waterloo Centre for Process Develop- ment, University of Waterloo	\$1,000,000 - 5 years	Oct. 31/83
12. Centre for Measurement and Control of Particles and Vapours, McGill University	\$1,000,000 - 5 years	Dec. 1/83
13. Canadian Centre for Advanced Instrumentation, Saskatchewan Research Council	\$1,000,000 - 5 years	Mar. 14/87
14. Canadian Centre for Fisheries Technology, Technical University of Nova Scotia	\$1,000,000 - 5 years	Mar. 14/87
15. Atlantic Coal Institute, University College of Cape Breton	\$1,000,000 - 5 years	Sept. 30/87

Source: Featherman, op. cit., IT&C (Jan. 1980).

University of Prince Edward Island, Memorial University in Newfoundland and the University of Saskatchewan are still in preparation.

Industrial Research Associations (IRA): Instituted by the Department of Industry, Trade and Commerce in 1973, the IRA program's objective is: "... to provide encouragement to sectors of industry to collaborate in supporting the establishment and maintenance of research and development facilities that deal with the range of technological activities common to the industry sector."

Four IRAs have been funded thus far (see Table 3). A fifth, a Canadian Plastics Institute, is being established. The Society of the Plastics Industry is to contribute \$200,000 per year, matched by the federal government. IT&C support is similar to that for the CAT program, but greater commitment is required from industrial firms and often from provincial governments as well. Although the IRAs are not directly affiliated with universities, their function involves contracting for academic expertise. They are research and service arms of umbrella groups of firms. For many reasons, this type of cooperative arrangement is relatively uncommon in Canada, although there are rare examples that have been initiated by industry.

Several industrial sectors have welcomed the development of these research associations, frequently because of a lack of proper inhouse research activity. Dr. Norman Eaton of the Welding Institute of Canada has pointed out that under the IRA program, supporting industries have a direct influence on priorities and financing, which they would not have if the research were undertaken in universities or governments (see also the arrangements surrounding POS, AOSTRA, VIDO and C-CORE in the case studies in the following chapter).

The Welding Institute, which has 115 corporate members, has created a unique MSc program in welding engineering, probably the first example in Canada of a joint MSc program between two universities with an industrial sponsor. Part-time students from the universities of Toronto and Waterloo attend courses at the two universities as well as at the Welding Institute.

The objective is to provide qualified research manpower for an industrial sector greatly in need of such skills.

Table 3: Industrial Research Associations

Association	Grant	Term	Termination
1. Sulphur Development Institute of Canada	\$2,174,000	8 years	June 30/81
2. Welding Institute of Canada	\$1,125,000	7 years	July 31/80
3. Canadian Gas Research Institute	\$ 875,000	5 years	Dec. 31/79
4. Centre for R&D in Masonry	\$ 900,000	5 years	March 31/84

Source: Featherman, op. cit. (IT&C, 1980).

The participating universities benefit by expanding their curricula, extending the scope of their professors' expertise and developing a network of potential contracts and sponsors for future research. It is obvious, on the other hand, that an arrangement like this among companies competing in the same market will raise questions of intellectual property. For this reason, common research efforts are likely to be limited to noncompetitive aspects of the industry, such as fundamental process innovation and improvement (rather than product innovation). Of course this often involves pilot plant and development work beyond the existing university capacity. Therefore, a major commitment from all three sectors is called for. The IRA model was adapted from the United Kingdom, which offers several models for major institution-building that may have a limited range of application in Canada. It is really an industrial program that, in these few cases, receives government support.

Management Advancement Institutes (MAI): A more modest program arose from the recognition that special problems surround the interface of universities with small businesses. In 1976, IT&C established two MAIs: at Université Laval

and the University of Alberta. The funding was set at \$50,000 per year for up to five years. The primary objective of the program is to provide research and other technical services to the small business community. The arrangement calls for the institute to generate revenue through consulting. It is a modest type of brokerage operation, blending some of the characteristics of TIS and IRI.

The University of Alberta MAI has a board of directors from several sectors, including private consultants and academics. As a further sign of its independence, the institute pays the university for use of its facilities. The local private consulting firms voiced concern prior to its establishment as to the potential for unfair competition, a common problem for universities in this type of arrangement and one reason for their preference for the arm's-length type of institution. Nevertheless, the Alberta Institute has developed excellent relationships with the university's Department of Engineering. The resulting structure is something akin to an Industrial Innovation Centre, described below.

Industrial Innovation Centres (IIC): Following their success in developing Industrial Research Institutes, Waterloo and École polytechnique submitted new proposals in 1978 to the Department of Industry, Trade and Commerce. Their ideas were also influenced by the Innovation Centres Program of the National Science Foundation (NSF) then operating at MIT, Carnegie-Mellon and the University of Oregon.²¹ IT&C responded with startup funds for two Industrial Innovation Centres, whose objectives are:

1. to stimulate an increase in the quantity and quality of technological innovations developed in Canada in the form of new products, new processes or new businesses;
2. to make greater use of the resources contained in university and community college systems, strengthening the performance of small and medium-sized Canadian technology-based businesses and evaluating and commercializing inventions from private inventors;

3. to encourage and support the entrepreneurial activities of Canadians in their efforts to start or expand technology-based companies.

One can discern an evolutionary chain of development from Office of Research Administration to independent IRI to a much more intense involvement with industrial technology in such forms as these innovation centres, which introduce entrepreneurship and innovation into the university curriculum, and a real involvement with commercialization and entrepreneurship in industry. The centres were also to assist students and faculty in developing technical concepts into new products, new processes or new businesses. The University of Waterloo was already providing this service through its Inventors' Assistance Program, partially funded by the federal government through Canadian Patents and Development Limited. This program is being integrated into the new centre, along with the Enterprise Development Program and a funding arm that assists in the development of promising ideas - Technological Development Inc.²² The innovation centres also provide small and medium-sized firms with specialized advice and assistance from students and faculty in the development and commercialization of technical ideas and inventions. This is a feature of the NSF program as well and has generated numerous consultations there.

The centres at Waterloo and Montréal are providing courses and conducting research on entrepreneurship, research management and innovation processes. Both centres have solicited cooperation from nearby business and management schools. The University of Waterloo has linked up its technical expertise with York University's Business Development Centre. A similar partnership has been formed between École polytechnique and Université du Québec à Montréal, with some marketing studies being undertaken at McGill University. This networking of resources at several universities in response to the evolving demands from industry has great potential for encouraging specialization among campuses; at the moment no mechanism exists for coordination in this area.

Discussion on this program has focused primarily on its independence and control. One of IT&C's criteria is a board of directors from small and medium-

sized businesses, university administration and government. It has been argued that such a large and diverse board might lead to delays in decision-making, and that to be a successful experiment the centre must retain sufficient flexibility to respond to day-to-day problems. On the other side, it is argued that such centres should be as free of university or government control as possible. The extension of this argument is that innovation centres should not be associated with universities in the first place because of the lack of necessary entrepreneurial and management expertise.²³ The more serious issue in the debate, however, is the ultimate extent of industrial influence in academic research.

At the moment there is an attempt to formally link the innovation centres to university initiatives in developing spin-off companies. Waterloo had already, on an informal basis, spun off some 26 companies. Through this more formal instrument, several new enterprises have been initiated, and new technologies licensed to existing enterprises. The Centre d'innovation industrielle Montréal, has 10 spin-off ventures to its credit.²⁴

Contracting-Out: The Science and Professional Services Directorate

The Department of Supply and Services, which is the central purchasing agent for the federal government, established this Directorate (formerly called the Science Centre) in 1973 to implement the contracting-out policy for the science and technology requirements of all government departments. The Directorate is currently responsible for also implementing policies designed to give Canadian content preference in some \$2 billion worth of instrumentation or engineering services contracts placed each year through DSS. The policy of contracting-out government science and technology requirements, and indeed the idea of a central agency for this, originated with the Glassco Commission and originally favoured suppliers strictly in the private sector.

In 1976, the policy was extended with four new guidelines covering (1) existing or ongoing as well as new requirements; (2) all scientific activities as well as R&D; (3) some areas of social sciences; and (4) a program of "unsolicited proposals" that had proved particularly useful in a

two-year trial. Industrial performers in the private sector remained as the preferred clients; alternative performers are to be selected on such criteria as their capacity to transfer the resultant technology to industry, as well as regional development potential.²⁵

The preference accorded industrial performers is a source of irritation among the hybrid institutions established at various points between university and industry. It places university centres at a disadvantage by excluding them, but they are possible recipients of several other programs of NSERC and DRIE discussed above. Of the remaining institutions, only the wholly supported industrial consortium type of industrial research association appears to qualify for preferred status. The multitude of remaining contract research agencies such as C-CORE, POS and others reviewed below, along with Provincial Research Organizations, are in a kind of noncategorical limbo - perhaps critical to the ultimate success of the federal programs, but treated as non-existent by this policy instrument.²⁶

Another problem with the present arrangement, as already noted, is that the responsibility for evaluation of contracted work is left to the contracting department. These shortcomings are important because of the size and potential impact of the operation. As noted, the whole Science and Engineering Procurement Service is now worth over \$2 billion in contracting each year, and in 1982-83, the Science and Professional Services Directorate placed 3449 contracts for R&D and related activities worth some \$216 million. This is roughly comparable to the research support budget of NSERC (\$226 million in 1982-83). Fifty-two per cent of the total amount went to the service sector of industry, and 24 per cent to secondary industry (although the latter contracts were individually large, representing just 7 per cent of the total number). Universities were grouped with all non-profit institutions and received about 18 per cent of the total value of these contracts. We cannot separate the hybrid institutes from these figures, but the Provincial Research Organizations, set up precisely to transfer technology to industry, received in total only three percent of federal contracting-out monies, slightly more than the amount shown for private individuals.

The effect of the new guidelines has been to increase the share to the originally intended recipients - industrial clients, particularly in the service sector - and to cut the share to individuals. The university share has also diminished over the years and, from the point of view of university-industry transfers, it appears that the whole family of hybrid institutions that we have called "research factories"²⁷ has largely been disowned by this policy, and left to become self-supporting on industrial contracts. Spin-off companies rather than hybrids are favoured by this policy. Contracting-out is similar to the corresponding instrument of R&D tax incentives in that it has considerable potential for assisting hybrids, but that potential remains unrealized.

Policy Instruments of Provincial Governments

We have already noted some of the central constitutional "givens" that constrain provincial as well as federal initiatives in linking university research activities to industrial needs. Universities, at the time of Confederation, were not cosmopolitan research institutions; rather, they were very regional, often sectarian, educational establishments that were only beginning to respond to industrial research needs. The Constitution placed them squarely under provincial jurisdiction, while centralizing all important economic powers and sources of revenue in Ottawa. By and large, universities have successfully resisted attempts by provincial ministers of education to use the distribution of operating grants as an instrument to encourage minimally some degree of specialization, or even centres of research excellence. However, in cases of mounting deficits where special operating grants are required, provincial governments have now made these conditional on the planning of specialized university activities.

These operating grants made possible the rapid expansion of faculty in the sixties: the number of full-time Canadian faculty members grew from 7,000 in 1961 to 20,000 in 1971 and has levelled off now at about 35,000. The assisted research portion of university operating expenditures reached a high of about 14 per cent in the mid-sixties, and thereafter declined to about 10 per cent. The university research and teaching establishment in science and engineering,

roughly comparable in size to the federal research establishment in full-time equivalent research (even when all graduate students are excluded), can therefore be taken as a given in the provincial science policy arena.

The idea of turning this scientific resource to the task of industrial development and technological innovation has always been popular with provincial governments. However, they have lacked the resources to develop linkage programs in assisted research similar to those of federal agencies, although the closeness of provincial governments to universities and firms would have eased the implementation of these programs. Moreover, until recently, provincial governments showed little interest in central advisory agencies for science and technology. As a source of Gross Domestic Expenditures on Research and Development (GERD), provinces supply only about 5.6 per cent. The main policy instruments for provincial governments on the university-industry frontier have been Crown agencies. The first generation of these was established somewhat along the lines of the National Research Council, but with differences that are important from the industry-university perspective.

Provincial Research Organizations (PROs)

The Alberta Research Council (ARC), founded in 1921, was the first of the provincial science councils and foundations. PROs now exist in all provinces except Newfoundland and Prince Edward Island: the Ontario Research Foundation, founded in 1928; British Columbia Research Council, 1944; Nova Scotia Research Foundation, 1946; Saskatchewan Research Council, 1947 (an earlier version was discontinued in the Depression); New Brunswick Research and Productivity Council, 1962; Manitoba Research Council, 1963; and Centre de recherche industrielle du Québec (CRIQ), 1969. The Newfoundland Oceans Research and Development Corporation (NORDCO) is an evolving science agency of Newfoundland, which, like the early NRC, lacks a research facility.

All the PROs have had direct and informal links with universities, and several are located at or near university campuses. Their mandates vary in detail, but they invariably call for the development of industrial technology

with supporting provincial economic development policy, sometimes with a science policy advisory function. In Alberta, ARC was deliberately instructed "to ascertain more definitely the mineral resources of the country and the possibility of their development." Besides direct contracting with industry, PROs have developed unique pilot plant capabilities in the academic milieu and have evolved technical advisory committees to bring industrial advice to bear on research programs. However, their involvement with universities has been largely informal and incidental, mostly limited to transfer of manpower and supervision of student theses, but including occasional shared use of the pilot plant facilities. The PROs were a first-generation industrial machine in the university environment, not well designed and not really intended to convert the arts and science college into a technical university.

Extensions of the Crown Agency

Provincial governments have been using the Crown agency instrument not only to carry out resource policy but, as in Québec, British Columbia and Alberta, to link those resource industries to university research facilities. For example, the Institut de recherche d'Hydro-Québec (IREQ), has an entente with several Québec universities. University students and faculty conduct research at IREQ, and Hydro's research personnel advise on thesis subjects and give courses at the master's and doctoral levels.

A system of cross-appointments is employed in a partnership between Bell-Northern Research and l'Institut national de la recherche scientifique (INRS), a para-government research institute associated with the Université du Québec. The resulting partnership, INRS-Télécommunications, was formally created in 1976 and permits an active collaboration of professors and students with industrial researchers. Recently, the Institut succeeded in establishing a jointly administered course program at the postgraduate level with McGill University.

Collaboration with McGill is the result of a conjunction of factors, including the proximity of the university to the INRS-Télécommunications laboratories, informal contacts developed by the Institut director who also is

a professor of electrical engineering at the university, and research expertise in telecommunications systems within the academic institution. This linkage of university research to the specialized and valuable research facilities of major public corporations, particularly in resource development industries, appears to have developed from similar kinds of linkages in the Provincial Research Organizations.²⁸

The Heritage Savings Trust Fund in Alberta produces an annual investment income of about \$1 billion, a significant part of which has been committed to provincial research and education programs. The Alberta Oil Sands Technology and Research Authority (AOSTRA) is a Crown agency without laboratories that funds an extensive research and training program involving all three sectors. (Greater detail on this is provided in a case study in the following chapter.) It is a most important provincial policy instrument, which has been used to initiate several effective linkage activities involving the technology of heavy oil recovery. That it is technology-specific is significant; it is a significant development on the PRO model, which is a more generalized provincial Crown agency instrument.

In Ontario, the Board of Industrial Leadership and Development (BILD) was established in 1980 at Cabinet level to initiate programs of economic development. One of these has been the recent establishment of six high-technology centres with a fund of \$128 million over a five-year period. They include a microelectronics centre in Ottawa, a CAD/CAM facility in Cambridge near Waterloo and a robotics technology facility in Peterborough. More recent additions include an automotive parts technology centre for St. Catharines, a resources machinery development centre in Sudbury and a farm equipment and food processing centre in Chatham. The main function of these projects appears to be to assist in the technological development of local industry, although the location decisions exhibit considerable political interest. Similarly, the university involvement may turn out to be more predatory than collaborative.

Another part of the BILD program now operating is the IDEA Corporation (Innovation Development for Employment Advancement). Apparently the Corporation will be able to negotiate for intellectual property, including the purchase or licence of technology, and provide venture capital. It is too soon to determine whether the necessary technology assessment and planning is going into the decisions of such a corporation to approve projects or to what extent, if any, university linkages will be built in.

Because of the large capital outlay required for meaningful development work in industrial research, the Crown agency obviously offers an immense opportunity for university-industry liaison. The Québec and Alberta agencies have been very innovative in this respect. Obviously the location of these facilities at or near university campuses is an important factor. Frequently, the university connection is actively sought not because this is in the mandate of the Crown agency, but because of the specialized needs for research-trained scientists and engineers, for which special university programs often need to be developed.

Action Concertée

The Québec Ministry of Education initiated a program in 1970 called "Formation de chercheurs et action concertée" (FCAC). The name came from France, but the idea is North American and closely tied to the institution-building requirements of Québec science. The program has seven elements: groups and seminars, research centres, major programs, service organizations for research, assistance to publications, general grants and formal "actions concertées." Rather than spreading limited provincial research funds across the NSERC spectrum, the program concentrates on particular projects and gaps in projects, using individuals and resources in university, industry and government.

A leading advocate of this program, the former director of Noranda's Centre de recherche, defines these projects as "multi-disciplinary collaborative efforts between the three sectors of the scientific community to solve technically complex problems that involve a high degree of scientific uncertainty and are of demonstrable economic significance to the economy of the country or

of one of its regions."²⁹ Dr. Gauvin goes on to describe one of these concerted projects in plasma technology, involving the participation of the universities of Québec at Chicoutimi, Laval, McGill and Sherbrooke, Hydro-Québec and l'Institut national de la recherche scientifique. The project is now in its eighth year and has had some success. A pilot plant installation has been developed, five doctoral and three masters' theses have been completed under the program at McGill University and several papers have been published.

One of the most significant aspects of the "action concertée" venture is that "it spreads the risk of failure over a number of partners, thus spurring Canadian industry to take a more entrepreneurial attitude towards research." This program exhibits some of the genius of the Associate Committees of NRC, but it is more adaptable and more specifically project-oriented than these and thus offers the possibility of advance negotiation of intellectual property.

Only four projects were initiated in the first ten years of the program, so its success in formal institution-building cannot yet be judged. One can see problems here, in comparing it with, say, AOSTRA, the Associate Committees and the US experience with contracting directly with universities for major program facilities, in that it might often become an innovative institution in search of an organizational home. However, on the initiative of university and government entrepreneurs, such a home seems now to be under construction, in what are variously called research or innovation parks.

The Research Complex

The concept of the municipal industrial park is established in the industrial development activities of provincial and local governments. By providing serviced land complete with the necessary power and transportation infrastructure, and by negotiating favourable tax and leasing arrangements, provinces and municipalities have often been able to attract industrial facilities.

At the same time, several universities have been producing spin-off companies that often are technology and research-intensive and naturally would

prefer to locate on or near the campus. Provincial governments have frequently come to look at the location of their Provincial Research Organizations (and of other technology centres with which they are directly or indirectly involved) as a development decision with great potential. In the fifties, this type of planning was influenced by the centrally planned "scientific city" concept in the Soviet Union and Hungary.³⁰ The removal of the Ontario Research Foundation from the University of Toronto campus to form part of Sheridan Research Park in Mississauga is an example of the influence of this fifties approach. Support facilities are there, as at an industrial park, but the essential prerequisite for a functioning complex of research factories, an interactive research community, is missing. The Sheridan planners effectively precluded that type of organic development by locating the park at a considerable distance from the existing university-based research complex, and selecting laboratories in areas of science and technology completely different from each other.

The research park, like the industrial park, is not itself a triggering device that will automatically bring about a rich interactive complex of research institutions. In the most successful cases, it is both an administrative umbrella over a complex of institutions that is expanding for other reasons, and a set of infrastructural support facilities and services that may be shared and will encourage further expansion. Examples of these facilities and services would include computer and information utilities, relevant engineering schools, instrumentation centres and the necessary support for technology transfer activities. The park can work as a focus for the many programs that are described in this chapter. The research complex is always systematic in the sense that it is much more than the sum of a number of separate research facilities, but how much more depends heavily on planners to put together a systemic and even symbiotic collection of research activities.

Two of the more interesting cases are the research park at the University of Calgary and the Saskatoon Research Park at the University of Saskatchewan. In both of these, described in detail in the following chapter, the Crown agency is important as a triggering device. SEDCO (the Saskatchewan Economic

Development Corporation) is now active in the development of the Saskatoon Research Park (a \$6 million investment), but it has of course been preceded by the Institute for Plant Biotechnology (formerly the Prairie Regional Laboratory) of NRC and the facilities of the Saskatchewan Research Council. An agency like SEDCO is in turn able to encourage the location of additional provincial laboratories such as those of Potash Corporation and others. Many hybrid institutions of the type we have called research factories are located on the 80-acre Saskatchewan site, with varying degrees of involvement with the university and industry.

The research park authority can become much more of a marketing and brokerage agent for the whole complex than it is at present. The preoccupation with administration and finding prospective occupants in the early stage of growth subsequently turns to a concern with marketing the resources of the complex itself, finding new sources of contracts, performing liaison with the university, and helping to develop new and unique support services for the circulation of information and technology transfer. Obviously the triggering device must involve some means of channelling investment into research facilities; government agencies with responsibility in this area should consider locating an office in the university based industrial research complex.

Research Manpower Transfers

British Columbia and Québec have introduced some interesting variations on programs that link university and industrial sectors through the movement of research manpower. In Québec, the ministère de l'Industrie et du commerce has instituted a program to transfer graduates to industry, called the "Programme de subventions aux P.M.E. manufacturières" (UNI-PME). Small and medium-sized firms apply for subsidies to employ graduate students. The provincial government pays \$10,000 of the salary of a university graduate with one degree, and \$12,000 for a postgraduate. Unfortunately, the program operates under a small budget (\$2.1 million for 1983-84). As with similar programs at NSERC, the best marketing approach has yet to be found; several universities and many Québec firms are not aware of UNI-PME's existence.

Also inspired by NSERC programs, the BC government has implemented its own version of an industrial postdoctorate program, \$25,000 per year being paid to a collaborating company for up to two years. Another provincial experiment in manpower transfers, the BC program of Graduate Research in Engineering and Technology (GREAT), involves a subsidy to graduate students of \$11 500 per year for up to three years.³¹ The award holders go to work on applied research projects for industry that are at the same time acceptable for MSc and doctoral programs in the province's universities. The constitutional jurisdiction of provinces with respect to universities is an advantage here and, from the point of view of the university, as in the university-inspired initiative at Waterloo, a fabric of interaction is eventually built up through the successful implementation of programs involving manpower transfer with industry. Again, the closer working relationships of provincial government departments with universities and firms should permit them to use such policy instruments as are described in these two sections on government more effectively than federal agencies have been able to do.

Regulatory Instruments

Government laboratories often were created to provide the necessary scientific support for the regulatory function of an agency or department of government. For this reason, many government laboratories are, quite properly, structurally insulated from the regulated industry. This separation from industry can encourage the laboratories to undertake basic investigations as an adjunct to their regulatory duties. Many excellent federal laboratories are in this category; the Inland Waters Directorate at Burlington, Ontario is a fine example. In the United States, on the other hand, much of the lucrative field of regulatory science - for example, in the Food and Drug Administration and the Environmental Health Protection Agency - is regularly contracted to third-party laboratories, often located at universities. This enables them to maintain expensive up-to-date testing facilities of great relevance and value in industrial research and development. This type of testing facility, such as a specially controlled environment, is frequently needed to develop industrial products. An example of this was brought to our attention by the Veterinary Infectious Disease Organization (VIDO) in the Saskatchewan complex,

where animal vaccines requiring extensive, controlled testing are under development. However, departments of the federal government have been slow to strategically locate these facilities at university research parks and to subsequently contract some of the related regulatory work to them. Enormously expensive animal research facilities have recently been constructed by the Department of Agriculture, but they are largely located near Ottawa.

Therefore, what we call the "regulatory instrument" is presented here in the provincial section, not only because provincial departments tend to contract more of this work into their PROs, but also because, particularly in the oil recovery research complex in Alberta, one can discern an interesting extension of regulatory powers into fields of research policy. The regulatory instrument may operate as follows: by itself acquiring some research capability in the area to be regulated, a regulatory agency is in a position to set very specific standards in an industry, standards that may in turn require increasing technological sophistication on the part of industry. Thus, even major oil companies, facing the special conditions and corresponding recovery standards of Alberta, have found it difficult and later impossible to meet the conditions of their drilling agreements from technology developed in their Tulsa and Houston laboratories. They have had to buy into the work of the research factories in the complex (by taking out industrial associateships for instance), and eventually they have come to locate extensive research and pilot plant facilities in the province.

The regulatory process has been frequently studied;³² indeed, this subject is now almost a growth industry in public and business administration circles. Despite all this it has apparently gone unnoticed that rewriting the rules of the game (a process that to the institutional school of economic historians is the main engine of change) can alter fundamentally the technological sophistication of an industry. Such an alteration can be costly and destructive, or it can become the basis for world-competitive instead of locally protected industries. Alberta apparently tumbled onto this by accident in its efforts to regulate gas flares and other gross inefficiencies in petroleum recovery. (We note this below in the case study.) There is no

reason that technological sophistication should not become a widely used parameter of regulatory practice, just as, at present, it is a widely ignored parameter.

Tax incentives are largely in the hands of government accountants, and by the same token, the regulatory instrument is most often wielded by government lawyers rather than scientists. As Newton and others observed, it takes science to make science, and as a consequence, this is a much-ignored instrument for developing industrial technology in all regulated areas, from oil recovery to communication systems. In our concluding chapter, we shall relate this point to the controversial area of government purchasing, another government instrument in which the technological possibilities have frequently been ignored.

Policy Instruments in the University

Although many kinds of university linkages with industry may be proposed and promoted by governments, all observers agree that their chances for success depend heavily on the attitude of the university to industrial technology as a form of knowledge. Engineering fought its way into the university curriculum at the universities of Toronto, New Brunswick and McGill late in the 1850s, with some difficulty and a number of setbacks. At that time, university science was still in the hands of generalists who were unqualified to give applied science courses, and demand from industry for graduates with this sort of training had not yet developed. As in Britain, the whole field of industrial technology was developing outside the university, and initially it was institutionalized on the outside as well.³³

The biomedical sciences present a qualified exception to this rule, and strong linkages of medical schools to teaching hospitals and research clinics were established at an early stage. The world-renowned complex of medical research institutions in Montréal is an example of these linkages. However, outside the special case of the Connaught Laboratories in Toronto, an effective linkage of this excellent base in biochemistry and medicine to biomedical

engineering and to industrial activities in pharmaceuticals, instrumentation and prosthetics has yet to become established in this country.

The real breakthrough to at least a first generation of relations with industry came with the establishment at McGill of a network of complementary exchange between the university and the Montréal business community. We have earlier noted that this relationship was institutionalized when business people joined the board of governors, a development followed by substantial business endowments for faculty and facilities in the sciences and engineering. McGill had already adopted the Scottish model of a university curriculum, and rejected the system of autonomous denominational colleges that is the pattern of the older English universities. McGill's resources were thus organized in a secular way around increasingly specialized faculties. (This became the essential pattern of development of most Canadian universities when, late in the century, the effectiveness of the German and American concept of specialized research training in the graduate school was demonstrated and later adapted to the Canadian university.)

This type of university interacted with industry by means of direct representation of the business and professional community on the boards, and often on advisory and professional accreditation committees. In return, the curriculum would include the type of education that would ensure a continuing supply of graduates with expertise relevant to business. The essential aspects of this exchange were more gradually introduced at the denominational universities, conditions varying across the country according to the extent of established clerical and governmental influence.

Some new universities that were established to accommodate the student expansion of the sixties, particularly Waterloo, Sherbrooke and the Université du Québec, show the influence of American state and technical universities. Essentially this meant bypassing the traditional development of a full curriculum around a dominant core of arts and science faculty, in favour of more specialized facilities, often around a core of engineering and related sciences. Interaction with industry then became much more direct, and these

universities more readily adopted industry as their clientele for an expanding range of services. Unlike the American model, however, where government became established during World War II as the most important part of the research clientele, in Canada government took on the essentially passive role of patron of the new university-industry relationship.

Relevance and Quality of Programs

With the professionalization of much scientific and technical knowledge, and the adoption - whether gradual or abrupt - of an industrial clientele for the university's output of knowledge and expertise, a subtle but deeply significant shift has occurred in the criteria by which the excellence of university programs are judged. In formally accepting evaluation by professional accreditation boards, universities have extended the principle of peer evaluation beyond the scientific communities and into the marketplace. One can argue persuasively that the standards of professional communities present a healthy input to university programs, and indeed they have influenced medical faculties since the Middle Ages. Nevertheless, professional standards are different from the intrinsic criteria of excellence imposed by scientific peers within a research community. Particularly in engineering, accreditation is one of the most fundamental ways in which the university has been effectively drawn into the industrial milieu.

University deans of applied science can turn bad news from an accreditation board into an effective policy instrument. The cost per student in professions such as medicine and engineering is much higher than average; competitive salaries and equipment costs in industry are likewise high. These problems have long since been dealt with in medicine, which has its own research council and sources of funding, a separate university budgeting system and an extensive system of access and cross-appointments in clinics where expensive equipment is often part of the health care budget. Many similar kinds of arrangements are emerging within engineering, but the institutions for achieving this are primitive compared with those in medicine.

In the period of physical expansion of universities, 30 per cent to 40 per cent of capital costs were devoted to the purchase of equipment. But as the NSERC Task Force on Research Equipment pointed out, resources have not been available for replacing and updating this equipment. In addition, the normal interdepartmental competition for operating budget within the university leaves professional schools unable to compete with industry for faculty and graduate students and therefore relatively short-staffed. As a result, in recent years accreditation boards have frequently reserved full approval of many engineering programs.

Among other uses, this can be an important bargaining chip within the university for deans attempting to increase the research capacity of their faculty. Aside from forcing necessary budget increases, recognition can be sought within the university for industrial experience and patents, giving these the same credit in tenure hearings they would have with professional accreditation boards. Outside the university, particularly for schools with developed industrial networks and advisory boards, this can be a starting point from which to build the industrial relevance of programs through all available linkage mechanisms. Chief among these are the direct and creative use of industrial research facilities and personnel.

Industrial Cooperative Programs

An early initiative in the new relationship with the industrial clientele was an attempt at Waterloo to increase the relevance to industry of undergraduate education. Undergraduate engineering students began working one semester per year in approved industrial settings. The success of the idea caused its diffusion to other departments and universities, so that by 1982, after 30 years, some 15,000 students from 22 universities were involved in this type of program.³⁴

An interesting variation on this idea brings participating firms to the university on a fee-paying basis. For example, the workshop on value engineering in the Department of Mechanical Engineering at McGill presents students with real-world industrial design problems, including marketing. The

organizers of such programs build up a network of industrial contacts that is invaluable for other linkage programs such as the movement of faculty into industrial sabbaticals.

Evolving the Industrial Office: Liaison, Brokerage and Advisory Functions

The successful operation of cooperative and other programs that transfer faculty and students to industry and move industrial researchers into adjunct professorships and thesis advisory work will eventually lead to contracting, consulting and licensing activities quite beyond the usual capability of a University Office of Research Administration. (These were generally introduced into Canadian universities in the mid-sixties.) Into this kind of prepared environment, the Department of Industry, Trade and Commerce launched a number of the successful Industrial Research Institutes discussed previously. In many cases, the IRIs simply institutionalized something that was already well underway, under the initiative of an evolved industrial liaison office or office of research administration.

An effective industrial office or institute within the university not only administers contracts and keeps track of exchanges within a network of industrial contacts, it also actively markets the resources and expertise of the university to its industrial clientele, acts as an information exchange and organizes the input and support of industrial advisory committees.

A Window on the Park

We have discussed some of the kinds of services and linkage activities that can usefully be "added to" the duties of a university-based industrial institute. They range from the Inventors' Assistance Program, sponsored at Waterloo by CPDL, to negotiating and assisting in the licensing of university technology, and incubating new companies, possibly in the nurturing environment of a research park. However, the relation of the university to spin-off companies is controversial and varies from one campus to another.

One example is a type of small contracting or consulting company, such as Contech ETC, which got underway in the energy conservation field at Carleton.

The university insisted on an arm's-length arrangement, refusing to allow Contech to occupy campus space, or to use the university name, staff and credit (Contech has to raise capital at market rates). Surprisingly, despite this cautious relationship, the firm is a wholly owned university corporation. At the other end of the support spectrum, spin-off potentials at Waterloo get evaluations, courses in entrepreneurship, access to facilities and contract research staff, access to venture capital and preferential rates in the campus research park. University of Saskatchewan's SED Systems Limited was a university-owned telecommunications venture, spun off from accumulated faculty expertise. It did not become independent of the university until it began generating sufficient revenues. The spin-off phenomenon is not uncommon; however, like patents and contract revenues, it is an indicator of the success of university-industry liaison rather than its cause.

There are options permitting a traditional university to experiment in a limited way with an industrial clientele without taking great entrepreneurial risks. It can open a window on the industrial research park, for a time enjoying the view. As one example, the University of Toronto has established an Innovations Foundation, which is intended to aid in arranging licences and spin-off companies and eventually to manage contracts. It is unique in that the university has undertaken to set it up as a separately budgeted unit, based on the Connaught Fund and private subscriptions. Thus insulated from the university budget, it may accumulate a capital fund that can in the long run be used to fund promising innovations in the university. For a time, this could serve as a kind of industrial observation window retaining options for the traditional university with a vast investment in academic science and a sense of uncertainty about its industrial clientele.

In the longer term, this type of option is not very stable. In other words, if the window on industrial technology remains open, the university takes in more than the view, repugnant as that may seem to some. The industrial institute is almost certain to expand on its initial mandate if it is to be effective. It will accumulate revenues as well as expertise and become, perhaps, an information centre that accumulates and channels information about

the knowledge resources and requirements of both university and industry. Then (at least with respect to the engineering faculty) it will take on brokerage and marketing functions, attracting contracts from new sources in government and industry and stimulating university spin-offs.

At about the point where a research park would be necessary to accommodate spin-off companies and evolving research factories, the university will be forced into some soul-searching about industrial technology. Up for examination will be university policies on consulting, patents, royalties, spin-offs, the off-campus industrial curriculum, tenure and so forth. In the face of the industrial challenge, we do not know of a traditional university with an arts and science core that is willingly evolving into a technical university; the scenario seems unlikely in this country. The percentages are heavily in favour of abrupt and even Luddite attempts to close the window at this point. But the marriage of science and technology was more than a wartime convenience, and before the moment of decision will have been reached, many of the remaining knowledge resources of the university will have been drawn into the socio-economic maelstrom. No doubt some of the university could still return to the cathedral school, the Chartres, of its childhood,

... patiently remote

From the great tides of life it breasted once,

Hearing the noise of men as in a dream.

Science in a Cold Colony: Industrial Options

Many weighty documents are extant on the subject of industrial research and technology in Canada, and the difficulties faced, particularly by manufacturing firms, in becoming more innovative and more competitive. Such a literature is to be expected in an emergent society struggling to gain control of its own economy. The literature is instructive in several respects: (1) we cannot assume that the innovativeness, productivity and market potential of a firm bears any direct or immediate relationship to its research department, if indeed it has one. (2) Nor can we assume that the environment and feeding of

industrial technology present at all the same class of problem from one industry to another, nor from one size and ownership status to another.

Industrial Scientists and Engineers

If one generalization is possible on the subject of industrial technology, it is that all surviving industry is becoming more technology-intensive over time. The primary resource sectors are not exceptions to this. When Sir John A. Macdonald lamented the disappearance of our virgin forest resource down the Ottawa river, the industry was based on the sale of squared timber to Europeans. The current production of pulp and paper products runs on low-grade softwoods and a high quality of chemical engineering input. To remain competitive, firms must maintain a sophisticated workforce just to do the defensive research and engineering necessary to absorb and develop new process technology, to maintain quality and to engage in new product design and marketing.

The increasing sophistication of the workforce undoubtedly represents the most important impetus to industry-university linkage. Industrial demand for highly qualified manpower has led firms into the cooperative educational programs, transfer of scientists and university advisory activities already described.

Endowments, Industrial Chairs and Fellowships

In addition to their recruiting activities, larger firms have often funded university fellowships and faculty chairs in areas relevant to their industry, as have foundations based on industrial wealth. Occasionally entire laboratories have been outfitted by industrial patrons, as for example at McGill University and the University of Toronto. Alternatively, one can find more recent examples of off-campus university teaching and research supervision in the industrial milieu. For example, engineering at the University of Alberta makes use of the oil sands facilities at Fort McMurray in its off-campus special curriculum. But the guiding principle in such cases has been maintenance of university control of the program.

Occasional chairs are also endowed by industrial consortia, and industrial philanthropy of this sort has been encouraged by government tax incentives and matching grants. In general, however, because of state patronage of Canadian universities, the latter have not been as aggressive or as successful as American universities in raising community funds and exploiting the patronage of their industrial clientele. During the expansion of facilities in the 1960s, a system of matching grants worked rather effectively, although complaints were often heard that this took planning decisions out of the hands of universities. Some consideration might well be given to making real increments to the annual provincial operating grant conditional on commensurate increases in industrial funds. Such a move would clearly favour those universities that have already cultivated their industrial networks for other purposes.

Industrial Research Associations (IRA)

We have already discussed this form of linkage as a program of the Department of Industry, Trade and Commerce. But other formats are possible and in fact the first such association in Canada resulted from an industrial initiative to take over a government laboratory at McGill University. Of course, active industrial involvement is an essential ingredient for all the linkage instruments discussed in this chapter, although the incentive usually comes from government or university.

The Forest Products Laboratory of the federal Department of the Interior was located at McGill in 1913. The Canadian Pulp and Paper Association wished to take over this laboratory and, with a bequest from Mrs. E.B. Eddy, McGill joined in this effort. Thus PAPRICAN was established in 1925 as a trisectoral cooperative agency, with an industrial laboratory at McGill, an endowed chair, a graduate research program and 11 otherwise competitive companies contributing in proportion to their production.³⁵ More recently, the Canadian Gas Association established its own research institute, with an IRA grant from the Department of Industry, Trade and Commerce. The Sulphur Development Institute is another example.

The key problem for such an institute is to identify a generic research program of an industrywide, nonproprietary nature such that all member companies can benefit from it and support it. In a thoughtful paper on the Canadian Welding Development Institute (an IRA resulting from a 1973 joint initiative of industry and IT&C), Norman Eaton described the range of technology transfer and development services possible within the concept of a generic technology centre.³⁶ The essential problem for institutes of this type remains one of identifying an area of nonproprietary technology that is still of importance in the industry. Other hybrid institutions (the POS research factory at Saskatoon is one example) have found this easier to manage by doing proprietary work under contract, and providing generic services to paid-up members who do not in turn control the institute. Also, generic technology in the form of major testing equipment (the wind tunnels are an example) are frequently developed by government agencies. The problem in that case is to explore ways of making these government facilities available to industry.

Industrial research associations must therefore be regarded as an industrial instrument that only occasionally is appropriate in the Canadian situation. In the few cases where industry groups have been influential in establishing research associations, they have not shown a great interest in locating them on university campuses.

Contracts and Industrial Windows on University Research

The relative lack of industrial interest in the university as a relevant source of research activity can also be seen clearly in the level of industrial funding of university research. Although technology and science are deeply interdependent, the science-dependency of industrial technology does not translate directly into an extensive linkage to university science. This point was reinforced in preliminary studies of patent citations to the scientific literature.³⁷

Even though direct contracting into Canadian universities has a long history, the amounts are not yet significant and do not appear to be increasing (see Table 4).

Table 4: Industrial Funding of R&D in Universities and Private, Non-Profit Organizations in Natural Sciences and Engineering as a Percentage of GERD

Year	Percentage	Year	Percentage
1982	.06	1972	.10
1981	.08	1971	.09
1980	.07	1970	.06
1979	.07	1969	.05
1978	.08	1968	.06
1977	.08	1967	.05
1976	.08	1966	.05
1975	.09	1965	.06
1974	.10	1964	.07
1973	.08	1963	.09

Source: Statistics Canada, Performer Surveys.

Moreover, the available evidence strongly suggests that the distribution of industrial contracts has concentrated on a few universities, although the total was only \$2 million for 1982. An additional \$1 million went to private nonprofit institutions, which includes several of the hybrid type discussed here. By contrast, the comparable US level is more than twice as high as in Canada (that is, in the order of \$250 million spent by industry on R&D in universities, and a similar amount in nonprofit institutions). This clearly implies that the relevance of science in American universities is perceived by industry in a way that is wholly different from that which prevails in Canadian industry.

Windows with a Privileged View

It is easily seen that Canadian industry has reservations about the relevance of university research and the institutions that constrain it. Contracts with individuals in university are often an unsatisfactory linkage instrument on

both sides and for many reasons. Straight consulting on existing expertise is seen as moonlighting on university time. Where the contracted work is original and therefore tolerated if not encouraged, other barriers await. The time limits of industrial projects usually present a problem not only for teaching professors, but for graduate students involved in thesis work as well; secrecy may also present a problem for the faculty member; the nature of the work and its outcome are always problems for his tenure committee, and its eventual relevance to profitable innovations is obviously problematic for industry as well.

In certain cases, faculty transfers into industrial laboratories have improved the situation, also overcoming the problem of irrelevant university equipment. Indeed, one such transfer at Bell Northern recently led to a formal arrangement whereby a valuable industrial facility for fabricating prototype computer chips can be used by university faculty and graduate students across the country. This is now coordinated by the VLSI (Very Large Scale Integration) Implementation Centre at Queen's University, and is currently the focus of large-scale government support. The Canadian Society for Microelectronics has been created as a result.

The action concertée has also been an effective instrument for a few Québec firms in developing particular projects and involving university people where relevant facilities would not otherwise be available to them. Although we have presented this as a provincial government instrument, the action concertée really calls for a major initiative and commitment from industry as well.

Finally, a particularly controversial development has surfaced at several US universities. In research areas such as biotechnology, where possible industrial benefits are huge but where uncertainty is also high and the relevant science is new and highly volatile, large firms attempt to control that risk by buying some form of privileged access to an entire university facility. Part of the price may be partnership in the construction of the facility. One entrepreneur, who recently sold outright his medical instrument company, has created out of the proceeds a family-controlled biomedical

research centre at MIT. The centre will employ one-third of the biology faculty, including a Nobel laureate, and own all the intellectual property they may develop.³⁸ It will come as no surprise at this point that Waterloo is the only Canadian university to have attracted this kind of interest.³⁹ (As we have seen, Waterloo is an exception in many respects.)

On the assumption that "what we have in this country is a failure to communicate," a proposal was made that a sort of private brokerage function be established, with subscribing universities and relevant firms put in touch with each other for a fee.⁴⁰ A market study for such an operation was funded, and eventually the University of Guelph retained an outside consultant for this study. It was found however that where universities actually want to be involved with industry they already have developed brokerage offices of the sort described. The fact that the consulting industry is moving into the field of university/industry liaison is a measure of the desperate situation that has been reached.

Clearly, the industrial sector has reservations about the relevance of university research, the available facilities for carrying it out and the institutions that constrain it. Our investigation, particularly in the case outlined below, leads us to single out three areas of special concern: the standards and procedures for performance and evaluation; the procedures for circulating results; and the system of rewards.

The resolution of all these sources of conflict and change is not obvious. One can observe the evolution of a new class of hybrid research institutions, belonging neither to industry nor to university, but heavily dependent on both. We refer to them as research factories. Several of them are described below, but these and more have been initiated by some combination of the policy instruments and programs described in this chapter.

VI

THE TECHNOLOGY RESEARCH COMPLEX: SELECTED CASES

The discussion in chapters 2 and 3 indicated that scientific knowledge and technical knowledge are increasingly and intimately connected and interdependent, but at the same time science and technology have become institutionalized in quite different forms. Universities have only rarely and with the greatest difficulty been able to actively involve themselves with research in industrial technology.

We have reviewed a large number of policy instruments available to all actors wishing to develop more effective university-industry linkages. An important general conclusion to emerge from the preceding chapters is that serious work on this front involves a major institution-building effort at all institutional levels, from the normative arrangements for intellectual property to special requirements for pilot plant and demonstration facilities. In this context of an evolving research complex, we can usefully explore the effectiveness of various policy instruments and programs. For our purposes, a complex is simply an interactive set of institutions for the development of science and technology in particular fields. It need not have been planned as a complex, and it need not be centrally located. We shall focus on selected cases of the university-based complex with relevance to industrial technology.

The Saskatoon Complex

The University of Saskatchewan at Saskatoon is the site of an extensively evolved complex of research institutions, whose development is closely associated with the wheat economy of the province and its continuing problems of diversification.

Grain prices in Europe began increasing rapidly in 1896; this, together with greatly diminished ocean freight rates, an enlightened homesteading policy for Crown lands and, of course, the completed transcontinental railway, touched off a period of rapid settlement in the Canadian west. In a brief period, indeed by 1913, a million new settlers had come into the prairie grasslands, increasing the occupied lands from four to 28 million hectares, and the wheat production from 530 000 to 5.8 million tonnes. Within that same period, Marquis wheat had been developed for prairie conditions by the Saunders dynasty in several Dominion experimental farms, principally at Agassiz, BC and Ottawa, and by 1913 was available in quantity to all growers.¹ Thus science took its place in the economic life of the northwest frontier.

The University of Saskatchewan

The university was established in 1909 through the efforts of Dr. Walter Murray, the first president of the university and the first of several important institution-builders on the local and the national scenes. He preceded C.J. Mackenzie in a series of important Saskatchewan linkages with NRC. Murray was named chairman of one of the earliest NRC experiments with the Associate Committee instrument - the Committee on Plant and Animal Diseases - which he convened in August 1917.

Their immediate problem was to develop rust-resistant strains of the new Marquis wheat. The loss to the 1916 crop due to rust had been estimated at 100 million bushels, and from 1916 to 1930, rust losses averaged \$25 million per year. The plant-breeding part of the program got underway immediately with a series of NRC grants to Professor Thompson in the biology department. Eventually, large-scale plant-breeding facilities were constructed by the federal Department of Agriculture in 1925, and a major program was launched and orchestrated by NRC and the department through the Associate Committee.² Rust-resistant strains were finally developed in the mid-thirties.

The diffusion of relevant science among industrial users has always been a central problem for linkage institutions, and this is particularly the case in agriculture, where innovating farmers far outnumber innovating firms in other

sectors. The provincial networks of agricultural representatives and experimental farms have been designed to perform this technical information service and, in Saskatchewan, they are joined by many outreach activities of the university. An early example of diffusion techniques was the use of a "discovery" train to visit farmers and discuss with them new scientific and technical developments. More recently, the university received a \$25 million grant from the federal Department of Agriculture to enhance its diffusion activities, particularly with respect to water management.

Much of the Saskatoon complex has evolved around the problems of plant and animal diseases and the development of alternative crops and industry in the province. For example, the Western College of Veterinary Medicine was established there in 1963 by an agreement between the federal government and the western provinces. As in the earlier case of the Rust Research Laboratory at the University of Manitoba, this type of agreement permits the location of major development and testing facilities in a university milieu. Before considering the development of some of the newer institutes and research factories in the food complex, we will refer to the university's spin-off activities in other areas.

Under the able leadership of Chalmers Jack Mackenzie, the College of Engineering took on a number of difficult research problems. One of them had to do with the corrosive effects of alkali ground waters on the concrete used in the bridges and buildings across the prairie. Mackenzie led a committee of the Engineering Institute of Canada and an Associate Committee of NRC to look at the problem himself, teaming up with Professor T. Thorvaldson of the Department of Chemistry and Chemical Engineering. To cement they added materials that would increase its resistance to the disintegrating effects of alkaline water. The results eventually led to the manufacture in 1931 of "Kalicrete," a sulphonate resistant cement patented by Canada Cement Co. Ltd. Mackenzie's work in this area included the design and supervision of two bridges in Saskatchewan. This practical approach stood him in good stead with the NRC of that period; in 1939 he was named to succeed General Andrew McNaughton as President of the National Research Council.

The university has provided a security blanket for several spin-off companies, including Develcon Electronics in the communications field, Startco Engineering in digital controls and Senstek, who produce industrial weigh-scales. One of the most successful university spin-off companies in the country came out of the Department of Physics; we will consider it in greater detail.

Northern Light Industry: SED Systems Inc.

As part of the cooperative research activities for International Geophysical Year in 1957, several Saskatchewan physicists became involved in spectroscopic measurements of the aurorae (northern lights), using rockets fired from Fort Churchill. At the same time, the Defence Research Board (DRB) made funds available to establish the Institute of Upper Atmospheric Physics at Saskatchewan.³ Subsequent grants from NRC, together with DRB contracts, helped established the Institute in the field of instrumentation for rockets, and by 1966, a rocket was launched for which the university had developed all instrumentation.

Dr. Kavadas, head of the Space Engineering Division (SED) of the Institute, then began developing much of the payload requirement for the Churchill Rocket Range, managed by NRC. SED thus became an expanding space industry contractor, and SED Systems Inc. separated in 1972, taking up rooms in some deserted RCAF buildings near the Saskatoon airport. SED Systems is organized in three groups: the Advanced Systems Engineering Group and the Satellite Communications Group have projects in aerospace communications, instrumentation, Telidon and control systems; the Commercial Products Group specializes in agricultural instrumentation and in earth-receiving stations, where it has enjoyed a major share of the world market.

SED's financial link with the university has weakened over the years; the university now owns 38 per cent, employees and friends hold 20 per cent and the Province owns 42 per cent through Crown Investments Corporation. The president, Alex Curran, was until recently Assistant Deputy Minister for space in the federal Department of Communications. The NRC connection is still

important, but SED is now a large-scale operation, with \$26 million in project revenues contracted in 1982-1983. It has clearly acquired "chosen instrument" status in Ottawa circles.⁴

The usual student and adjunct faculty links are exercised with the university, although, like other firms, SED perceives many difficulties in maintaining any level of contracting into the university. Operating under contract time and making arrangements for necessary controls on information seem to be the main problems. SED likes having first claim on the top engineering physics graduates at the university, and may move some of its Systems Engineering Group to Innovation Place on the campus.

Institute for Plant Biotechnology, NRC

Returning to the development of the main institutions of the food complex at Saskatoon, we observe another key NRC linkage. General McNaughton, president of NRC, sent his division head for biology, Dr. Robert Newton, on a tour of universities in the west in 1939. Their concern was the development of the technology necessary to obtain industrial and chemical products from grain and straw surpluses. (This approach, which became popular for a few years, was termed "chemurgy" and parallels to some extent the current interest in biotechnology, which is recaptured in the namechange from Prairie Regional Laboratory.) Dr. Newton recommended a separate facility to be established as a western regional laboratory of his own division.

Wartime measures precluded these expenditures, but the Associate Committee on Grain Research was able to start up a small group on oilseeds in the Chemistry Department at the University of Saskatchewan. This work received an impetus from two important political sources as follows. Rapeseed oil was then imported from Asia and used as a lubricant in steam-powered marine engines. When the Asian supply line was threatened, C.D. Howe, Minister of Munitions and Supply, became interested in quickly developing a Canadian substitute crop for wartime use. At about the same time, J.G. Gardiner, the long-time western minister of agriculture, wired Treasury Board, insisting "... that an item of five hundred thousand dollars be placed in the supple-

mentary estimates for the construction and operation of a western laboratory to study the industrial uses of agricultural products."⁵ Treasury Board acted on this, cutting down the amount and placing NRC in the coordinating role. Mackenzie and his able colleague Dr. W.H. Cook consequently formed the Prairie Regional Committee (note 77). It was given strong regional representation and placed under the chairmanship of Dr. Newton, who had by then left NRC to become president of the University of Alberta. They were able to obtain acceptance of the idea of a specialized university-based centre for

... the utilization of agricultural and other natural products; further that where processes reach a stage in this laboratory or elsewhere that gives promise of a profitable utilization in this region, pilot plants be established at appropriate points; all the foregoing to supplement work done by the National Research Council, the Dominion Department of Agriculture, and the universities.⁶

Thus was established the basis of a family of linkage institutions capable of performing essential development work in fields of technology related to the economic development of the region. The research strategy of the lab (known as the Prairie Regional Laboratory, and recently renamed the Institute for Plant Biotechnology or IPB for short) promptly focused on the major problem of cyclic surpluses in the wheat economy. Industrial processing of the wheat surplus and byproducts preoccupied the popular front here; unfortunately, the economics of this approach have always been undermined by necessary assumptions about transportation costs and the uncertain future of the so-called "Crows Nest Pass rate." With the recent removal of the Crow rate, at least one barrier to industrial processing on the prairie has been removed. The importance of pursuing a strategy of diversification and alternative crops in an uncertain economy based on wheat has been apparent to westerners for some time.

Although a fibreboard plant was successfully developed to make use of the straw surplus, the strategy of developing alternative crops quickly gained precedence, and long-range work on rapeseed got underway. This involved plant

biochemistry at IPB and the plant breeding facilities of Agriculture Canada, and industrial cooperation from grain marketing agencies and the Toronto laboratory of Canada Packers. Working closely with the nutritionists in regulatory science at the Food and Drug Directorate, and with biochemists at the university, IPB devised new analytical techniques for determining the composition of oilseed. As new strains were developed, the expertise and technology were transferred to the Agriculture Canada laboratory in the Saskatoon complex for routinized analysis.

In the implementation of this successful program, several factors emerged. IPB developed a research strategy in the context of a careful and realistic analysis of the local economy. The institution-builders found a serious gap in existing relevant research capacity; they developed a regional institution with the independence and resources necessary to pursue a long-term program involving both basic science and extensive collaboration at the demonstration stage. IPB collaborated with the university in making staff available for teaching duties in the early years, and in the development of relevant expertise. The recruitment of expertise has not been perceived as an important problem, because the market for this type of highly qualified personnel has not expanded rapidly. Students do not circulate through the laboratory and it seems that the university has not enjoyed direct access to its facilities.

The problem of evaluation and recognition for work in applied areas at IPB has been resolved in the following way. It is acknowledged that much of the work may not result in research papers, and that the work may be of a very long-term nature due to the development of new and relevant processes. Hence the director periodically writes an appraisal of each investigator's activities and progress, taking these factors into account, as well as possible spin-offs and benefits to the local economy.

In order to evaluate IPB's research program, a task force will be struck from time to time; the inhouse work is then compared to other similar activities across the country. Recommendations are made, and in this way new opportunities for research may often emerge. Although IPB is intended as a

national facility, it has always been oriented to the prairie economy and thus has been involved with interlocking membership on the Provincial Research Organization boards in all three prairie provinces. Although this arrangement permits an exchange of information in a general sense, it is not a functional source of evaluative and technical input on IPB's research program. The early importance of IPB relations with the Associate Committees seems to have dwindled, and despite its interlocking advisory structure it runs independently with minimum outside influence.⁷

There is at the moment limited sharing of technical resources with other institutions in the campus research park, Innovation Place. Plans have been advanced with local support from both agencies and from Innovation Place management for locating IPB and the Saskatchewan Research Council in a single building with some shared services. Suggestions for jointly developing new capital facilities for testing and development work received a favourable response from all concerned. It was pointed out, however, that the computer facilities and requirements at IPB are somewhat specialized and either dedicated to running particular instruments or specially programmed for internal use.

By way of summary: IPB entered the Saskatoon complex at an early stage of its development, evolving a research strategy closely related to local industrial needs and not duplicated elsewhere. It performed as a catalyst in the research complex and contributed substantially to the local economy. But it appears that the extent of its collaboration has been a function of the interests of individuals rather than of the structure of the institution. One could also observe that it is easier to design collaborative and advisory arrangements into a new organization than it is to substantially alter established patterns.

Protein Oil and Starch: The POS Pilot Plant Corporation

In the late 1960s, it became clear to the grain industries, particularly those represented by the Rapeseed Association of Canada, that a pilot plant or demonstration project should be developed for oilseeds and other grains, which would promote the development of new technologies and fill the technological

gap between the raw material producers and the secondary finished food manufacturers. Otto E. Lang, a former dean of law at the University of Saskatchewan and, at that time, Liberal Cabinet minister responsible for the Canadian Wheat Board, appointed a Food Protein Study Group to examine the opportunities for increased Canadian participation in the manufacture and marketing of food proteins from grains and oilseeds. The study group published its findings during the 1972 federal election campaign. After reviewing a wide range of issues relevant to the food protein industry, members of the group were particularly struck by the "lack of post-laboratory facilities to assist in the translation of laboratory results to industrial practice."⁸ They therefore recommended that the government establish a multipurpose pilot plant capable of handling a wide range of grains and oilseeds and producing plant protein products in sufficient quantities to predict commercial costs and facilitate industrial evaluation.

At this juncture, the Grain Marketing Office of the Department of Industry, Trade and Commerce lobbied representatives from the food sectors, and at a meeting in February 1973 an ad hoc Industrial Liaison Committee was organized to consider the proposed facility. The site to be selected was a choice between Saskatoon and Guelph, each having the appropriate research expertise. As for IPB, the site selection was political, and in July 1973, the federal government announced at the Western Economic Opportunities Conference that it would fund the creation of this pilot plant, which would be located on the University of Saskatchewan campus. The POS mandate is to foster the development of new or improved technology for the production of ingredients from agricultural raw products; POS undertakes to do this largely by separating legumes, oilseeds and cereals into proteins, oil and starch (hence the name POS).

It was critical at the outset to obtain industrial sponsorship, government funding and university participation. The federal government guaranteed 90 per cent of initial capital costs to a maximum of \$4.5 million and agreed to provide some operating funds for the first five years. Obviously, to maintain its viability, the corporation had to obtain a commitment from the food indus-

try. This was arranged by offering membership to industrial participants. Full membership was given those organizations contributing \$10,000 and an operating fund commitment of \$5,000 per year for five years. Provincial governments were offered membership at \$100,000 and \$50,000 per year for five years. Finally, associate membership enabled small firms to benefit from POS research by contributing \$1,000 per year. POS also generated revenue through confidential contract work. Members enjoyed a 15 per cent (now 25 per cent) discount in fees for the use of the facilities and for contract work. The plant opened in 1977 with 24 members and by 1980 had collected \$2.5 million in industrial contracts and fees.

From this membership structure, a board of directors was set up with twelve members; seven industrial, two federal, one provincial, one university and one from a professional association. A Technical Advisory Committee oversees the inhouse research projects, which make up approximately 50 per cent of the work. Membership has grown very little, and the director, Dr. Dennis Jones, has initiated a campaign to attract membership from the food industry.

From the outset, marketing its expertise in the food industry has presented great difficulty for POS. A number of factors contribute to this. Although the food industry is product-competitive, it does not favour the introduction of innovative processes in its branch plant structure, which permits easy circulation of old equipment. Also, of course, much of the processing industry is foreign-owned. Coupled with this was the Crows Nest Pass freight rate, which contributed greatly to the lack of secondary processing in the west. During the debates that led to the passage of legislation to revise the Crow rate, POS was one of few western voices to be heard in favour of change. In the long term, POS may help create its new industrial associates on a local basis, but for now, it is difficult to market the facility among essentially US food conglomerates.

Among other startup difficulties is the fact that the university people often tended to see POS as a competitive rather than a complementary organization on campus, taking potential contract money away from their own individual

projects. Other laboratory facilities on the university campus viewed POS in a similar light.

As part of his marketing strategy, Dr. Jones has undertaken a survey of food industry interest in four provinces; he hopes to interest several provinces in sponsoring small firms for POS membership, as the governments of Alberta and Saskatchewan have done. POS does offer its facilities to non-members on a fee-for-service basis, with no capital outlay. Firms can contract either to use the pilot plant or to have work performed by POS staff. One problem that arises, however, in marketing a research institute based on contract work is that the details of past success are usually still confidential.

Networks of relations through manpower movements have not yet been built up to link POS to the rest of the complex and to potential industrial clients. The staff do not give courses, though the director has proposed a specialized course for food engineers and research students that may be offered in the facility itself. Contact has been made by way of coordination with food science at the Universities of Guelph and Manitoba and the Technical University of Nova Scotia (TUNS).⁹

Relocating even part of the food processing industry on the prairie may prove at least as difficult as getting oil companies to locate some of their research activities in Alberta. If so, however, it is not an impossible task, and POS might well benefit from the Alberta experience (recounted below). With respect to intellectual property, at least some of the AOSTRA model seems already under review in Saskatoon.

Patentable discoveries that arise from POS work are offered by exclusive licence to the company with the highest bid. Members of POS get first crack by submitting sealed bids to the board of directors. If no member has submitted a bid for a licence within six months, competition is then open to industry at large. The incentives for internal staff are not clear in this arrangement, however.

Contract work involves the problem of client firm confidence in FOS secrecy, as both parties are also in a sense competitors. One expects the future development of unique information and patent searching services, perhaps in conjunction with Innovation Place, and this will expand and routinize relations with the clientele. Certainly an invention evaluation program could bring in many smaller firms. FOS relations with federal and provincial departments have also not yet evolved very far, perhaps because the federal government acted through the Wheat Board in establishing FOS. The regulatory instrument has not been used very effectively to influence firms in this sector. The science associated with food industry regulation could be a source of core funding and new expertise for FOS. The relation of FOS to the biotechnology expansion of IPB will be important and remains to be worked out.

The Veterinary Infectious Disease Organization (VIDO)

This research organization is similar in structure to FOS, but its history is rather different. In 1973, Dr. A.E. Pallister, then vice-chairman of the Science Council of Canada and adviser to the Devonian Group of Charitable Foundations, approached the council's executive director, Dr. Patrick McTaggart-Cowan, with the idea of sponsoring industrially relevant research organizations. The resulting collaboration became known as the "Calgary Initiative." Proposals were solicited from several groups for highly focused research institutions in areas ignored by governments.

One proposal was for a Centre for Cold Ocean Resources Engineering (C-CORE), developed by Dr. Angus Bruneau of Memorial University, and this eventually received the backing of the Devonian Foundation for funding (see the Newfoundland case study below). Apparently, it was McTaggart-Cowan who inspired the idea of university locations, eloquently referring to the academic linkage as "the authority of knowledge." He apparently assumed in this strategy that knowledge would be conferred by the university on prospective industrial researchers, rather than the other way around. Another proposal was from a veterinary medicine group, which included Dr. C. Bigland of the Western College of Veterinary Medicine and Dr. O.M. Radostits of the University of Saskatchewan. Their proposal, in August 1973, was for a Canadian Veterinary

Microbiological Institute, with its research focus on the common diseases of food-producing animals. This area was poorly developed because federal research agencies tended to concentrate on the so-called "statutory diseases," that is, those involving heavily regulated exotic diseases. The group pointed out that the more common diseases lead to much greater economic loss than regulated diseases, even though the latter usually involve health hazards to the public. In August 1975, an agreement was negotiated between all parties involved to establish the Veterinary Infectious Disease Organization (VIDO) on the Saskatchewan campus.

The Devonian Foundation agreed to fund VIDO for five years, total operating and capital grants not to exceed \$2.2 million. It was felt that after this period VIDO should be self-supporting or have attracted sufficient funds from other sources to remain viable. The market was to provide an acid test for VIDO's importance; failing there, it was felt, it did not deserve to survive. The Government of Alberta made a capital grant of \$1.87 million and the Government of Saskatchewan agreed to give operating grants over five years totalling \$1 million. The University of Saskatchewan provided VIDO with the land and support services for the building, and agreed to pay the director's salary. VIDO was to be a component of the Western College of Veterinary Medicine; in fact, the director was then a professor at the college. In this way, close relations between VIDO and university research could be maintained.

Initially located in a two-trailer "satellite laboratory" of the university, VIDO next rented some laboratory space in the Canada Agriculture Animal Pathology Building on campus, while waiting for the construction of its own facilities, officially opened in October 1978.

Although the ideal setting for such research on common livestock diseases was felt to be the university, it was evident to VIDO's creators that VIDO research staff had to be free of administrative and teaching responsibility to enable them to focus on the research problems at hand. This recognition of the need for independence is at the root of the creation of both VIDO and its sister organization, C-CORE.

VIDO's ten-year research plan has now been put together on the basis of major disease areas identified by the food producing sector. VIDO's recent success is in creating a vaccine, VICOGEN, that now controls from 30 to 50 per cent of mortality caused by calf scours. The vaccine was licensed in 1979 by Connaught Laboratories Ltd. in Toronto for sale throughout Canada. The initial revenue from this agreement has covered the costs of approximately 10 per cent of subsequent VIDO research activities. In 1982, Connaught Laboratories turned the marketing of VICOGEN over to an American laboratory, and since VIDO had not obtained a patent, the market is now shared among some ten foreign companies. Expertise in patent searching and licensing is coming to be recognized at research factories as an essential component of their information system.

The VIDO administration recently initiated incentive bonuses for research staff working on commercially viable projects. Five per cent of invention royalties is set aside for an invention incentive fund. The board of directors decides how much of this is to go as merit increases to staff. Funds that remain are distributed by the executive officer to members of the support staff. In this way, all staff can benefit from inhouse discoveries that lead to commercial application. In an attempt to preserve the integrity of its inhouse research, VIDO has established a spin-off organization, Biostar Inc., that will concentrate on manufacturing products or processes developed from inhouse activity.

As for relations with other organizations, the linkage with the Western College of Veterinary Medicine (WCVN) is a key to VIDO's complementary fit in the much wider picture of government research in animal diseases. Some thesis work is being performed at VIDO and supervised by WCVN professors. Discussions are underway between the two organizations regarding a joint curriculum in veterinary disease. VIDO is particularly concerned about the necessary long-range supply of research investigators. Two new programs are being considered: 1) a fellowship grant at the MSc or PhD level for university students to perform their research work at VIDO; and (2) a visiting fellowship program to draw top researchers in the field to VIDO. At present, great difficulty is

experienced in finding suitable researchers in Canada. The federal government's quota system allows a university only a limited number of non-Canadian academics per year, and it seems that institutions like VIDO, located on campus, are also subject to this restriction. Although this is a short-term hindrance to organizations looking for specialized talent, in the longer term it encourages more training programs of the kind VIDO is now considering.

VIDO has been forced to concentrate a significant proportion of its budget on disseminating the results of its research to food producers. A great deal of extension work aimed at the farming community is undertaken. Fact sheets describing various diseases and their prevention have been widely distributed, and journals of the livestock associations have been used to inform the food producing community as well. These vehicles are also effective in drumming up financial support for VIDO. Because VIDO has no core funding from which to support its long-range research projects, it relies a great deal on contributions from individuals, and livestock breeding associations.

Although it does not operate on an industrial membership basis like FOS, the range of support is very impressive. By 1981, VIDO had received contributions from some 84 industry associations, in addition to 14 grants from western provinces, the Devonian grants and 15 research grants. Nevertheless, VIDO's concerted efforts to obtain some core funding from the federal government have not achieved any success. The only support from the federal government has been several grants from the NRC and NSERC and one science procurement grant from Agriculture Canada, amounting to about 4 per cent of total funds raised by VIDO. One of the major reasons for the incorporation of Biostar appears to be to allow VIDO access to hitherto unavailable federal funds.

The major issues faced by VIDO in realizing its ten-year plan are:

- (a) Core funding: VIDO is now virtually dependent on its year-to-year fund-raising. Core funding from larger organizations and the government would allow the organization to include longer range research goals and work more efficiently on short-term projects.

- (b) An animal testing facility: Canada apparently has no large animal isolation facilities that can be used by research organizations outside Ottawa for testing vaccines. As a rule, such a facility must be within the same metropolitan area as user organizations.
- (c) Manpower: Curriculum development at the university, as well as clearly defined policies from Employment and Immigration Canada, could alleviate some of VIDO's concerns in this area. Other research organizations have made use of postdoctoral appointments for strategic international circulation of talent.

The Saskatchewan Research Council (SRC)

About the same time that talks were progressing within NRC concerning the creation of a Prairie Regional Laboratory, the new Government of Saskatchewan was pursuing a policy of intervention and import substitution to build up secondary industry. The importance of science and technology to the provincial economy was foreseen, and a need identified for an organization that could (1) act as the research and development arm of the provincial line departments and (2) provide the government with information about the technical aspects of provincial resources and industrial activities. But by 1947, when the Saskatchewan Research Council was established, the Douglas government was already in full retreat from its interventionist program of resource development, and preparing for the 1948 election.¹⁰ Thus SRC did not become the "NRC" of an aggressive provincial government, as some had planned.

The concept of the council was not new. Alberta, Ontario, British Columbia and Nova Scotia had already established their respective research organizations. The only unique feature of the early Saskatchewan Research Council was its grants and scholarships programs with the University of Saskatchewan for mission-oriented projects. Lacking its own research staff and laboratory facilities, the SRC continued this program and little else for ten years. In 1958, several limitations became apparent: the program was dependent in magnitude on the availability of graduate students, and the work could not be easily geared towards the most urgent projects, nor to the application phase.

Consequently, a research laboratory was established at the university campus and SRC recruited a staff of about twenty.¹¹

The grants-in-aid and scholarship programs were kept intact, as it was felt that these would provide a critical pipeline to the main source of highly qualified manpower in the applied and industrial research areas. (A similar granting strategy was briefly adopted by the New Brunswick Research and Productivity Council from 1962 to 1965.) The selection committee itself is composed of the executive director of SRC and the two graduate deans from the universities of Saskatchewan and Regina. The criteria for selection are general: provincial relevance and compatibility with the current SRC research program. The amounts are not large: in 1981, SRC administered 18 grants totalling \$108,000.

Another feature of the SRC, this one shared by several of the other Provincial Research Organizations, is its location on a university campus. The rationale behind this decision was to link the scarce human and physical research resources in the province in such a way that they would be mutually complementary. The University of Saskatchewan and, in particular, its Faculty of Engineering, had had a long history of research in practical and industrially oriented problems. Present legislation governing the Council stipulates that at least three of its members must be from the faculties of the two universities in the province. The universities also contract work into SRC (\$200,000 in 1981-82), at about the same level as the SRC granting activity.

Although several facilities are maintained outside the university, the bulk of the work is carried on within campus grounds, and SRC has recently leased space from the Saskatchewan Economic Development Corporation (SEDCO) and constructed a resources research facility within Innovation Place. The facility comprises three sections. The first is a general purpose pilot plant that has been leased to the French uranium firm, Amok Ltd., now completing some work on the processing of uranium ore. The second section of the building is a larger pilot plant on a 10-year lease to the Potash Corporation of Saskatchewan, which has recently geared up a large R&D program. The final

component of the facility houses SRC's own chemical and radiation analytical services. The Slowpoke Nuclear Reactor for neutron activation analysis is also located here. These developments, of course, mark a new phase for both SRC and the provincial government, corresponding with the potash and oil boom of the 1960s.

Another feature of SRC is that it operates the Technical Information Service (TIS) for Saskatchewan, under contract with the central TIS office in the National Research Council (IRAP-F). The Industrial Services Division of SRC operates TIS as a field service on a free and confidential basis available to all secondary manufacturers and service industries. NRC funds the operation and SRC recruits the necessary personnel. The service originated in 1955 as part of NRC's larger TIS function in assisting manufacturers with solutions to technical problems, industrial engineering and relevant information sources. The program at SRC slowly expanded to include industrial engineering and some management consulting in product development.

The field staff of TIS undertake a considerable amount of "cold calling" every year; more than 400 firms were visited in 1981. This activity lends credibility to SRC, and requests for further assistance are not uncommon. In fact, TIS officers tend to monitor the development of particular firms over extended periods. They have also developed a computerized inventory of secondary manufacturing firms in the province and respond to occasional requests from Saskatchewan's Department of Industry and Commerce. From time to time, TIS refers back to the central TIS outlet at NRC Ottawa for information that is not available inhouse (though initial backup is the SRC and the university complex of research institutions).

The major sources of funding for SRC are the provincial government and fee-for-service work from the private and public sectors. Current expenditures in 1981-82 were just under \$10 million, 22 per cent of which was in research and 12 per cent in development. Ten task forces were constituted in 1980 to provide strategies for major programs; among other topics, they looked at

biomass, environmental enhancement and control, technology impact assessment, information collection and dissemination, and resource development.

SEDCO and Innovation Place

The long-sought diversification for the Saskatchewan economy appeared to have arrived in the 1960s on the wings of the potash boom. Canada briefly became the leading producer, and Saskatoon was known as the potash capital of the world. However, a virtual collapse in world grain markets in 1967 quickly demonstrated the dependence of fertilizer markets on the wheat cycle. Provincial net farm income fell from \$489 million in 1967 to \$202 million only two years later. The NDP was returned in subsequent elections, and the Blakeney Government took office in 1971, re-establishing a central planning staff and a policy of intervention in the resource sectors.¹² Two years later, a boom in commodity prices began; these included oil, potash and wheat. Saskatchewan Oil and Gas Corporation was formed that year, essentially to do exploration work. The 1975 elections confirmed this interventionist policy, and later that year the Potash Corporation of Saskatchewan (PCS) was formed and began acquiring about 50 per cent of the working assets of the industry. This set off a series of political and legal disputes, largely around the interpretation of resource ownership in Section 109 of the BNA Act.¹³

The Saskatchewan Economic Development Corporation (SEDCO) is a Crown agency that makes use of provincial resources to aid small business development and contribute to economic diversification. Much of its activity is loans, loan guarantees and equity investments, but SEDCO has also built up considerable experience in developing industrial parks. The University of Saskatchewan therefore approached SEDCO in the mid-1970s with the idea of developing a research park, adjacent to its campus, that would encompass the new pilot plant facilities of POS and VIDO and provide a management structure for the continued development of the whole research complex. It was established in 1977 and called Innovation Place.

In the initial phase, SEDCO leased 32 hectares from the university and constructed the SEDCO Centre, which houses the computer, the TIS group of SRC,

a consulting firm and the Potash Corporation. SRC and SEDCO have constructed the resources pilot plant next door. A third building, the "Incubator Mall," is under development, and will house spin-off companies still under the wing of the university. Philom Bios, a biotechnology firm developed by the former director of POS, is one of these.

The original visionary, Dr. Leo Kristjanson, is now university president, and the executive director is Dr. Richard Quittenton, who works through a Management Advisory Committee to attract and screen prospective tenants. The university retains a veto in this committee. SED Systems is interested in a CAD/CAM facility in the complex, and Northern Telecom may move its fibre optics group out to Innovation Place. The federal government's National Hydrology Institute will also be located there. Aside from reasonable terms for leasing space, of course, the involvement of a provincial Crown agency provides additional negotiating incentives for potential clients, who may benefit from provincial government purchases.¹⁴

There are more creative development incentives, such as those in the hands of provincial Crown agencies. Potash Corporation and Saskatchewan Mineral Resources Corporation, for example, have evolved a policy of devoting a percentage of profits to research. Through a joint agreement with the university, PCS is funding major research projects in four types of engineering - chemical, process, mechanical and geophysical. Initial seed money has been committed, and the subsequent arrangements appear to be modelled on AOSTRA relations with universities in Alberta (see below). PCS will provide an ongoing technical review of the work, and intellectual property and publication rights (usually within one year) will be written into the long-term industrial contracts.

Innovation Place may become involved in organizing liaison seminars to keep tenants informed of university activities. However, the more likely course towards common services would probably involve bilateral arrangements among tenants themselves. One possibility is for SRC and IPB to jointly

occupy a major new facility and share services such as computers, library and technical shops and services.

The Alberta Complex

In the development of their research infrastructure, Albertans have enjoyed the presence of many of this country's most talented institution-builders. H.M. Tory had already been at work in British Columbia on a satellite of McGill University, when he turned his attention to recruiting the first faculty of the University of Alberta in the summer of 1908. Including Tory himself as president and professor of mathematics and physics, the faculty numbered five in all; some 37 students appeared in September for registration. They got underway with a statutory budget amounting that year to \$25,000, raised through succession duties in the province.

Edmonton was still a fur trading centre and the last staging area for the Yukon gold boom, which lasted from 1897 to 1910. The main business interests, down on the CPR at Calgary, were led by R.B. Bennett and his partner, Senator James Lougheed. They led off in the long struggle to obtain provincial title to the resources on Crown lands. Business interests stood to gain, of course, but provincial ownership was also necessary to raise development capital in the province. Twenty years later, when Tory left Edmonton to again take up the task of institution-building, this time to create a national laboratory at NRC,¹⁵ he left behind a province that had a first-class university, but that had not yet gained control of its extensive resources. The cyclical wheat economy of Alberta and Saskatchewan could not sustain the enormous public debt taken on in the building (and subsequent financial failure) of regional rail networks. The abundance and diversity of alternative resources was eventually to present Albertans with an opportunity to diversify and industrialize their economy.

The Alberta Research Council (ARC)

The chief spokesman in support of developing alternative resources in the post-WW I provincial Cabinet was J.L. Côté. He was already interested in mineral development, particularly the vast oil sands at Athabasca, which had

been described by John Macoun of the Geological Survey of Canada while on an expedition in 1875 to find a northern route for the CPR. Tory had also been busy developing applied research in the university and, together with Professor John Allan, teamed up with Coté and his committee, the Alberta Industrial Development Association, on a number of initiatives. These included the Industrial Research Department in the university in 1920 and the Scientific and Industrial Research Council of Alberta early in the following year. The latter, eventually called the Alberta Research Council, was given a government advisory role and a budget with which to contract laboratory facilities at the university and initiate applied research into the industrial development of coal, oil sands, clay deposits and minerals. The oil sands pilot plant is an early example of the use of an industrial linkage to overcome the problem of industrial demonstration and testing, (see the section on AOSTRA below). Tory's departure for Ottawa made possible a cooperative program with NRC for work on gas, coal and oil sands. A Technical Advisory Committee structure for evaluation was also initiated at ARC.

Title to the resources was finally transferred from Ottawa just at the beginning of the Great Depression, although the collapse of commodity prices removed any immediate development prospects. The university connection was fortuitous for ARC during the Depression years; provincial resources were not available to sustain the Council, but senior staff were absorbed into teaching duties and managed to keep the Council alive and salvage at least some of the research program.

Like NRC in Ottawa, the Alberta Research Council served as an incubator for the development of the expertise and institutions necessary for industrial development of the resource base. Dr. Robert Newton, who had been director of the Biology Division at NRC and instrumental in establishing the Prairie Regional Laboratory, was dean of agriculture and then university president at Alberta in the forties. He was thus one of the all-too-rare linkage instruments between the ARC and his former colleagues at NRC and PRL. As well as being university president, he retained the position of research director and Council member at the ARC.

The university connection is now maintained in several ways: two Council members are nominated from the university sector, and though ARC has moved into separate facilities, the current long-range plan stipulates "exchange of staff, participation of graduate students in research programs, joint seminars, visiting professors, shared facilities and projects, university staff on the Research Council, advisory committees, employment of university staff as consultants and research contracts with universities."¹⁶ Postdoctoral fellowships, as a means to attract researchers, have been offered by ARC since 1958.

The Advisory Committee structure has been expanded into several subject-specific committees with industrial, government and university representation as appropriate, though often at a very senior level. From the very beginning, ARC has built or contracted for pilot plant facilities in order to bring its process investigations to a stage of industrial relevance and feasibility.¹⁷ The internal orientation at present seems to be industrial rather than academic, chiefly maintained by project-specific contracting, which accounts for more than half of the budget, and by a combination of the technical advisory structure and a direct linkage into the science and economic planning committees of Cabinet. In addition to operating TIS, the Council provides a full range of information services to industry, including the specialized services of the Oil Sands Information Centre. The driver in these activities has been the Alberta Oil Sands Technology and Research Authority (AOSTRA), discussed below.

ARC also operates a "do-it-yourself" program available to entrepreneurs who need assistance in developing an invention or innovation. The entrepreneur may lease space from ARC, and engineers, technicians and instrumentation are provided at cost. Although intended for small firms, the program has also attracted larger firms looking for an incubator to test new research projects. Once feasibility has been determined and the firm's own research labs are set up, the entire team can move out. Another feature of ARC is its method of technology transfer. Once the Council staff has developed a product or process innovation, a technical assessment contract may be given to an engineering

firm to assess the new technology and assist with marketing and further development. As with the technical advisory committees, the idea here is to invent an effective industrial form of peer evaluation.

The Energy Resources Conservation Board (ERCB)

The Alberta petroleum industry began in 1913 with Imperial's discovery of oil at Sheep Creek in the Turner Valley field, southwest of Calgary.¹⁸ D.B. Dowling of the Geological Survey had been mapping regional coal deposits within range of the CPR, and Survey reports had indicated the likelihood of oil and natural gas in the region. Close interaction with the industry followed, with Dowling's mapping activities drawing on the drilling records and, in turn, indicating the most promising places to drill. In this way, the Calgary operations of the Survey became an invaluable part of the industry and the evolving petroleum research complex in Alberta. Eventually, a permanent office and division of the Survey was established in Calgary, which became the Institute of Sedimentary and Petroleum Geology.¹⁹

One of the normative characteristics of the oil industry, which lends it so much colour and endears it to the hearts of Hobbesian individualists, is the rule of capture. Although 80 per cent of all oil is produced from Crown leases, the rule of capture provides ownership rights to the one who first brings oil or gas to the surface. The ensuing war of all against all was eventually regulated by a system of prorationing of production to stabilize the industry. The Province had been unable to enter the regulatory arena before the Crown lands were transferred from Ottawa in 1930. Once this was achieved, a major objective was to ease the wasteful recovery process, particularly the flaring of natural gas. "The fearful flares burned night and day and turned the country into what was referred to as 'Hell's Half Acre', a yawning chasm that spouted flames for 14 years until Alberta established a conservation board in 1938 with enough legal power to force operators to produce naptha and then crude oil in an orderly fashion."²⁰

The Petroleum and Natural Gas Conservation Board was established in 1938 by the Social Credit government of William Aberhart to prevent waste and fix production quotas, using a system of prorationing after 1950, and thus becoming a kind of government-sponsored cartel. Even this limited degree of intervention required the development of a rather sophisticated level of industrial knowledge, and the evolving conservation function drew the Conservation Board and ARC into the technology of the industry. ERCB, as it was reconstituted in 1971, now has extended authority to issue permits and set standards for the development of all provincial energy resources, including the developing petrochemical industry.

The Petroleum Recovery Institute (PRI)

The University of Alberta and the Alberta Research Council were closely involved in the evolution of these regulatory and support institutions. This was so because the evolving complex represented, and required for its operation, an accumulation of industrial technology outside the industry itself. This involvement of the provincial government permitted it to intervene in the pursuit of its major policy goals of secondary development and diversification. When the Alberta Gas Trunk Line (now part of NOVA, an Alberta Corporation) was formed in 1954, it was not intended merely as a device to export gas, but rather to get sufficient control for local industrial use and for the development of a petrochemical industry.²¹ The knowledge component in this whole process of secondary development has perhaps been more critical than all the others, though it seems to have been universally ignored in the political debates of economic historians.

Among the pioneers in the development of this family of institutions is Dr. George W. Govier, who had been head of the Department of Chemistry and Chemical Engineering and later dean of the Faculty of Engineering at the University of Alberta. He had been chief deputy minister in the Department of Energy and Natural Resources for some time, and was Chairman of the Energy Resources Conservation Board. During his tenure there, in 1966, the Petroleum Recovery Institute (PRI) was created. Established as an independent, non-profit research organization, PRI is in fact a joint effort between the

petroleum industry and the Government of Alberta. The central vision guiding its creation was that research in Alberta in petroleum recovery techniques could increase recovery yields and extend the life of the oil reserve. Furthermore, the creation of a specialized research institute would attract students to petroleum engineering, and this could eventually benefit the private sector. PRI is housed in the Energy Resources Research Building in the research park of the University of Calgary. It has two objectives: carrying out research aimed at increasing the recovery technology for oil and gas, and applying improved recovery methods in the field.

Despite its propinquity to the university, PRI's links to the institution are chiefly informal. The research manager is adjunct professor at the University of Calgary. The Board of Governors has an ex-officio university representative, and PRI occasionally lets contracts and research grants in the academic community.

Financing is provided from several sources. Over 30 petroleum companies are associate members, each contributing from \$1,500 to \$30,000 annually according to its oil production in Canada. The provincial government contributes \$750,000, and \$450,000 is obtained via the Canada-Alberta Energy Resources Research Fund. Industry also contributes \$100,000 in support of specific projects, in addition to the associate membership fee. AOSTRA contracts with PRI for oil sands research, as at the Alberta Research Council.

As at the Council, senior-level links with industry are reflected at the working level through a Technical Advisory Committee (TAC), allowing the organization to develop strong links with international experts as well. Institute projects are developed by staff, who then prepare proposals for evaluation by the committee, composed of industry, university and government representatives. Industry members are selected from local companies in Alberta and research firms in the US. The TAC is essentially a specialized peer evaluation committee that appraises research projects for technical merit and economic feasibility.

Industrial associate members obtain first chance at the results of research, and staff can publish findings after six months. If a patentable process emerges from the research, the institute must obtain a patent prior to publication. The usual procedure is to license innovations and obtain royalty fees. However, the institute's main purpose is to ensure rapid diffusion of technology in the industry. For contracted research, PRI may draw up confidentiality agreements with client firms. It may also undertake to field-test new processes by arrangement with industrial partners.

The Alberta Oil Sands Technology and Research Authority (AOSTRA)

The vast oil sands reserve has been at once the most visible and the most elusive of the natural resources of the plains, since the expeditions of Alexander Mackenzie in the northwest. It contains 200 times the recoverable reserves of conventional crude oil in Canada and twice those of the Middle East. Through difficult years, the Alberta Research Council maintained its efforts to develop an extraction technology. These efforts went through successful pilot plant demonstrations and led to limited commercial application when, in 1967, a subsidiary of Sun Oil established the Great Canadian Oil Sands plant near Fort McMurray.

The development of this resource is heavily dependent on technology and research, but there are many more basic economic and political considerations. Decisions are thus cast in a classic textbook case of the economics of gathering technical information as a hedge against the risks of enormous investment commitments. However, economists and politicians are seldom familiar with the subtleties of using knowledge as an economic resource. In the early fifties, the hard-won technology currently in use for surface-mining the oil sands was virtually given away to interested companies that had purchased leases but were under no commitment to develop them.

The great value of an industrial monopoly of technical expertise finally became apparent in the negotiations preceding establishment of the Syncrude consortium in the early years of the government of Premier Lougheed, 1971-1975. The sobering experience of those negotiations led to the formation of the

Alberta Energy Company as a provincial Crown partner in the consortium, and the creation of the Alberta Oil Sands Technology and Research Authority (AOSTRA). Both of these are Crown agencies, created from the oil revenues in the Alberta Heritage Savings Trust Fund.²² It is the mandate of AOSTRA to develop technology for recovery in the oil sands and heavy oil beds and for enhanced recovery from conventional pools. In this way, knowledge is used creatively as an economic resource.

As AOSTRA nears the end of its first ten years in 1985, it will have spent some \$250 million, plus revenues from the sale of technology, which now exceed \$2 million per year. It is not, however, the size of the research undertaking that is particularly relevant to university-industry linkages, but rather the innovative approach of the agency towards intellectual property and its development, evaluation and diffusion. This approach is completely unfamiliar in academic settings, but it appears to be effective in an industry that is renowned for competition and secrecy; and it is beginning to serve as a model for engineering faculties in several universities.

Dr. C.W. Bowman, chairman of the Authority, described its operation as follows: "One key ingredient to the AOSTRA method is that AOSTRA owns and controls technology." This permits serious joint research ventures with relevant companies. Then, perhaps reflecting on the difficult years of negotiating from a limited information base, he goes on: "Without a strong portfolio of its own proprietary technology and know-how we think our country will be in a poor negotiating position in the international market place."²³ AOSTRA itself does not conduct research nor does it have its own laboratories. Rather, its method of operation is by stimulating industry, university and government cooperation. Three main program areas have been developed to help achieve AOSTRA's mandate. The first and largest in dollar terms is the joint funding of demonstration projects with petroleum companies. Through a fifty-fifty funding arrangement, AOSTRA sponsors projects that test a variety of processes for improving recovery of bitumen in surface mining, improving recovery of heavy oils, and upgrading bitumen for use in petrochemicals;

finally, of course, AOSTRA orchestrated the major field pilot projects and demonstrations for in situ oil sands recovery.²⁴

The second level of AOSTRA contracting largely involves the Alberta Research Council, which operates the Oil Sands Research Centre as well as the Oil Sands Information Centre and a Sample Bank. The Research Centre has two test beds for testing and gathering data on the basis of physical models.

The third level of activity involves a variety of university programs, including extensive research contracting with university professors, as well as several university chairs and graduate fellowships.²⁵

By 1981, AOSTRA had spent about \$7 million on the university program, about \$11 million with the ARC, and \$110 million on its cost-sharing arrangement with industry.²⁶ However, by far the most important point about AOSTRA's program for university-industry linkages is the fact that the arrangements for control of intellectual property permit fairly extensive degrees of interaction among these three levels of activity.

In advance of all projects, shares of future royalties are negotiated and become part of the contract. The university research package may be accessed (that is, the knowledge is made available to them) by AOSTRA partner firms for about 5 per cent of its cost. Some 23 firms have taken up this offer. This policy increases the likelihood of innovations being licensed. Access to any one project within the package is offered at a fee of 25 per cent of its cost. Equipment acquired on university contracts belongs to the university.

Access to the patents and technical information produced from ongoing industrial ventures in the field may be offered to interested parties, or "consultative participants."²⁷ Their access fee is negotiated, along with the extent of access they will have to relevant existing technology and patents of the partner firm. Finally, the linkage involves the joint participation of relevant technical staff from university, ARC and industry in a series of technical evaluation and project management committees. Special conferences

of this sort are also convened by AOSTRA to review the state of the art in particular technologies and to plan future projects, such as an extraction test centre in the Athabasca field.

AOSTRA maintains all rights to patents and technology developed out of its research activities. By negotiating returns to participants and controlling access to the technology, it has been able to bring about realistic forms of interaction between, on the one hand, university professors working on projects worth tens of thousands, and on the other, historically the most secretive firms working on projects worth tens of millions. Apparently, only Imperial Oil has so far refused to enter into these proprietary arrangements. Although informal intellectual property arrangements of this sort have evolved elsewhere, AOSTRA was the first to effect this scale and degree of formality in advance. Secrecy provisions, particularly on site-specific work, along with long publication delays and contract deadlines, present difficulties that should not be minimized. But the prevailing and apparently successful strategy is the concept of advance negotiation by a powerful information broker.

The Computer Modelling Group (CMG)

CMG was established in 1977 essentially along the same lines as the Petroleum Recovery Institute, with which it shares accommodation on the Calgary campus, and under the auspices of the same institution-builder, G.W. Govier. The use of physical models of petroleum recovery from oil sands and heavy oils, as employed extensively at ARC, had involved considerable cost and delay. Some members of the Department of Chemical Engineering at Calgary recognized that these problems could be overcome by computer simulations. The form and difficulty of these are generally similar to econometric models, and they are so constructed as to be able to be updated with field test and physical modelling data.

Seed money came from the Canada-Alberta Energy Resources Fund, and AOSTRA has both funded CMG and supplied it with industrial partners. The director maintains his links with the university, and his board is provided with a Technical Advisory Committee, which meets twice a year and provides ongoing

industrial advice to the research program. CMG members and associate members are drawn from industry, university, ARC, AOSTRA and other agencies. They may acquire user status for simulation programs or purchase them outright at \$500 000 each. Associate members also may contract for inhouse work at CMG. The university allows inside rates for its computer utility; in return professors can use CMG's facilities free of charge.

An external measure of the relevance of this software was provided by Venezuela, which also has an extensive oil sands resource. When the single simulation packages were offered to members for \$1-2 million each, the Venezuelans acquired all of CMG's simulation software outright. If Canada is ever to break the monopoly that the California consulting giant Bechtel seems to have on project-managing our megaprojects, it will be through the exploitation of accumulated expertise and software on the scale of AOSTRA and CMG. The missing link in the necessary accumulation of technology may be supplied by the new research facilities of Petro-Canada and NOVA.

Unfortunately, the Alberta agencies in this complex have displayed little interest in the tremendous ecological effects of recovery projects, particularly in the oil sands. AOSTRA has only one small project of this kind, and ARC has also been largely committed to industrial problems. Consideration might well be given to funding an expansion of CMG's activities into ecology by acquiring the necessary software and expertise from the large-scale environmental modelling projects undertaken in the sixties in the United States.

Petro-Canada, NOVA and Private Developments in the Complex

As at Saskatoon, the research park at the University of Calgary is more of an umbrella over a successful existing complex than an engine to start one (which is the case at Edmonton). It is really an Alberta complex, the most important elements of which are the agencies described above; for them, the location is incidental. Nevertheless, Calgary is the head office location for 84 per cent of the country's oil companies, and many of them are locating research facilities in Calgary. The first of these was the Petro-Canada laboratory; it

cost \$10 million to build and equip this major facility in 1978. This fact, together with the forces that had been unleashed by the Conservation Board and AOSTRA, appears to have exceeded a threshold condition, whereby the major companies are beginning to perceive more and more difficulty in operating effectively in Alberta out of the technology and expertise generated in Tulsa and Houston.

Petro-Canada's mandate, much of it inherited from several acquisitions, includes the fostering of Canadian R&D in the energy field. Dr. George W. Govier was retained by Petro-Canada "to advise on research strategy, project priorities, staffing and methods of cooperation."²⁸ By 1980, the centre had a staff of 70, \$3 million worth of equipment, and an annual operating budget of \$5 million. It has several main research divisions: one in support of worldwide exploration activities; seven laboratories and two field pilots in support of in situ heavy oil and oil sands recovery; and process R&D.²⁹

Not to be outdone, the Alberta Gas Trunk Line,³⁰ which had moved into petrochemicals in the seventies, acquired 68 per cent of Husky in 1979 and became NOVA, an Alberta Corporation, the following year. Plans for a major NOVA research facility have been put together by E. Pallister, who, like Govier, is a seasoned institution-builder. A current project is the Canstar oil sands joint venture with Petro-Canada. However, NOVA is perhaps more properly seen as a chosen instrument of the Alberta government to bring about the petrochemical scenario for industrialization. Seen in this light, the NOVA laboratory might become part of a new direction in the Calgary part of the complex: this would involve another AOSTRA type of agency with Heritage funds and a mandate in the biotechnology field.³¹ Pallister is a key to these developments, but the planning is still highly secret and confidential. Shell Oil Company has located a major research facility in the Calgary research park as well, and the other major companies with oil sands interests have research facilities in the planning stages.

Following the reports of an NRC committee on the development of new or expanded uses of the sulphur that had been accumulating as a by-product of the

gas industry, an Industrial Research Association called the Sulphur Development Institute of Canada (SUDIC) was established in 1973. It has been a joint federal-provincial undertaking, under the IRA program of the Department of Industry, Trade and Commerce. Its structure is similar to other IRAs, with industrial sustaining member companies and an industrial board and representatives from the two governments. Its early success has been in developing industrial products from sulphur, and it is now moving into the environmental field with technology for reducing emissions of sulphur dioxide.

The most immediate effect of the rapid development of industrial laboratories at the university has been a crisis in the market for skilled manpower and research scientists and engineers. Serious salary differentials of 30 per cent have built up, along with extensive raiding of faculty and graduate students. The AOSTRA programs can do little to alleviate this short-term crisis. The Research and Development Authority of the research park could become involved in a major program to attract the necessary expertise into the area and coordinate their movement among institutions in the park.

The Research and Development Authority has commissioned a series of studies on areas of biotechnology into which it may be able to diversify. A multipurpose facility is also envisaged, with small laboratories for startup companies (there have been few of these in Calgary) and computer facilities, seminar rooms and conference facilities. The University of Calgary was a satellite campus from 1945 to 1965. The engineering faculty was established then as well. It is essentially a university with an arts and science core, and it has not yet found a way to adapt to the scale and magnitude of the industrial challenge surrounding it.

St. John's Evolving Cold Ocean Complex

Although the Irish monks and Norsemen who explored the Northwest Passage had no illusions about where they were, later Europeans who came to Newfoundland persisted for a very long time in thinking they had come to Asia.³² The resources of this first region of the country to be extensively explored remain largely unknown. Besides the strategic allure of the Passage itself,

which recurs from time to time, as in the fifties when it was virtually occupied by US defence forces on the DEW line, the resources of the vast circumpolar continental shelf have drawn a continuous stream of fishermen, explorers, traders and scientists into the eastern arctic for four and a half centuries.³³ It was, however, the inland resources of the Labrador peninsula that first brought Canadian scientists on expeditions for the Geological Survey.

Albert Low of the Geological Survey, working from a base camp at what is now Churchill Falls, studied the extensive water power and iron ore resources of the Labrador-Ungava interior in 1894.³⁴ Two problems have plagued the development of these resources: the physical difficulties of access and legal and political problems of jurisdiction.³⁵ An opening shot in the continuing Labrador-Québec boundary dispute was taken by Premier Maurice Duplessis, during the one audience he granted to Brinco executives, when he wondered aloud "... whether, in fact, the entire Hamilton River was in Newfoundland at all."³⁶

The same two problems of access and jurisdiction have hounded the development of the offshore petroleum resource, particularly on the Hibernia oil field in the Grand Banks. The field is located across ice-frequented and stormy seas. At the same time, federal and provincial claims in the area remain unresolved. The extent of the physical, regulatory and jurisdictional barriers to development has become painfully evident in the wake of the lost drilling rig, the Ocean Ranger. The Royal Commission of inquiry, chaired by Provincial Chief Justice T. Alex Hickman, found it necessary to make its preliminary scientific investigations in Finland and Norway, and to prevail on the goodwill of ODECO, the drilling company under contract to Mobil, to produce technical witnesses. From the point of view of ODECO and Mobil, the binding legal inquiry and subsequent lawsuits are in the United States, which was also the source of regulatory authority and inspection responsibility for the Ocean Ranger.³⁷ There has been great difficulty in getting oil companies even to locate liaison offices in the province, and the development of oil industry research facilities in the complex is a major challenge.

All of this has many parallels with the early situation in Alberta, and it is easy to conclude that Newfoundland is urgently in need of a science policy for the development of institutions like those just described in the Alberta complex. But for Newfoundland to consciously follow the Alberta model, at least two developments seem necessary. First, to use the regulatory instrument, federal and provincial governments must come to some agreement on the two major issues of jurisdiction and standards for resource recovery. Second, and more fundamentally, an enormous amount of science and expertise must be developed in areas related to the technology of resource recovery in the cold ocean environment. This in turn requires the involvement of unique research institutions, their internal linkage to education and training, and their external linkage to other Maritime research institutions specializing in such areas as marine biology and geosciences. A number of initiatives are ground for optimism that in fact this is just the course on which Newfoundland, and Canada, have already embarked.

A Home Port for Cold Ocean Engineering

Mobil Oil, in taking out exploration permits for the Sable Island area in 1960, set a pattern that other companies followed. Consequently, much of the eastern shelf was under permit by the end of the decade when discoveries began in the Beaufort Sea. These early efforts made clear that the offshore technology developed for the Gulf of Mexico and the North Sea would be inadequate for the Canadian situation. The Science Council of Canada issued a report in 1970 calling for a "major program" of research in marine science and technology, to be coordinated by a Crown agency.³⁸

Subsequently, a federal Task Force on Ocean Policy was struck and a number of reports issued. These included, in 1973, somewhat premature announcements of an oceans policy and attendant technologies. The MOSST announcement mentioned a "... plan to see that Canada controls the essential industrial and technological ingredients to exploit offshore resources." Emphasis was to be given "... a wide range of marine science and technology programs," including the "... development and maintenance of ocean engineering at universities and in government laboratories," all with the good intention that "Canada, within

five years, achieve world-recognized excellence in operating on and below ice-covered waters."³⁹

As the enormous institutional implications of this research policy began to be sorted out at the federal level, expectations were understandably aroused among interested research groups in the Maritime universities. One of these was the Ocean Engineering Group at Memorial University in St. John's. With the leadership of an energetic ex-Waterloo professor, Angus Bruneau, engineering at Memorial had adopted a cooperative educational program in 1968 and in the following year, obtained a five-year Negotiated Development Grant from NRC to establish the Ocean Engineering Group in several projects related to icebergs.

The group now has about 25 faculty and five graduate students working on some 20 projects, and it shares the facilities of the Marine Science Research Laboratory with the Newfoundland Institute for Cold Ocean Science, which represents about ten researchers from basic marine sciences in the university. The laboratory maintains some small-scale seawater tanks and research vessels at Logy Bay. The university now coordinates the activities of these three institutions, plus C-CORE (discussed below), through a Presidential Advisory and Coordination Committee on Ocean Related Research.

This study has noted some of the difficulties of developing engineering research programs through the machinery established to encourage traditional scientific disciplines. The case of the Ocean Engineering Group is interesting in this context, because the university seems always to have been very much in support of this undertaking. The Negotiated Development Grant mechanism has been criticized elsewhere for its discouragement of industrial partners. Again, this was not problematic in the early years of the group; oil companies have only recently begun contracting substantially into the university.⁴⁰ Nevertheless, the grant was discontinued in 1975, apparently because the projects were oriented towards specific sites and specific engineering problems rather than a program of basic science with which the NRC's Grants and Awards Division, now NSERC, would have been more comfortable.

The Ocean Engineering Group persisted, and a full graduate program in ocean engineering is now offered, both for professionals at the MEng level, and for research investigators at the doctoral level. A school of shipbuilding engineering has also been established, in 1979. All these programs are, in varying degrees, linked to the specialized research factories in the complex.

Centre for Cold Ocean Resources Engineering (C-CORE)

Back at the national level, where dreams were made, the ambitious oceans policy of 1973 began slowly to be translated into plans for necessary technology development and institution-building. Two of the critical studies in this translation seem to have issued from our Calgary institution-builder, A.E. Pallister, working under contract to NRC.⁴¹ But while the federal machinery moved in its slow course towards what was certain to be an ecologically controversial technology policy for resource recovery in the oceans, Pallister's position on the board of the Devonian Foundation and his activities and associations at the Science Council led to the so-called "Calgary initiative," which was more immediately fruitful. The initiative consisted essentially in a proposal drafted by Dr. Angus Bruneau, dean of engineering at Memorial, and also a member of the Science Council at that time, to establish a Centre for Cold Ocean Resources Engineering at Memorial with a startup grant from Devonian.⁴²

The proposal was for an institution similar in structure to the sister Devonian research factory, VIDO, in the Saskatoon complex. It would recruit its own full-time research staff and develop linkages both to the university and to industrial associate members. As Dr. Bruneau delicately put it, the experience of the Ocean Engineering Group with its Negotiated Grant had been, among other things, a learning experience.

What we learned was just how difficult it is to undertake engineering research in our northern ocean frontiers while meeting all the obligations and priorities associated with the operation of a teaching faculty. The schedule of natural events of importance in the research, the availability of ships and other logistical support and the extraordinary management

required for adequate coordination of complex programs with many parties involved, all imposed demands beyond what could be met by faculty members ⁴³

Thus C-CORE was established in 1975. Its purpose is ". . . to undertake engineering research designed to assist in the safe and orderly development and utilization of Canada's ocean-related resources. C-CORE shall concentrate its research activities on the solution of a limited number of carefully defined specific engineering problems that are clearly of national interest and of long-term concern to industry and government."⁴⁴ The constitution goes on to provide that C-CORE will proceed in its projects to the point where the viability of an idea has been demonstrated, and then introduce other organizations to its potential benefits. Industrial contracting is to be constrained; it is now at 30 per cent of the annual budget and considered too high by the other organizations in the complex, who are in fact competing with C-CORE for contracts. This level of contracting is necessary because the initial Devonian grant of \$1 million was designed to match funds from industrial associates in subsequent years in a diminishing ratio of 2 to 1, 1 to 1, and 0.5 to 1. The federal oceans policy of 1973, with its seductive call for a centre of excellence in oceans research within five years, was unfortunately still on the drawing boards when the core funding from Devonian expired.

The university connection and support were thus critical. Memorial owns the building and equipment and appoints the Board of Governors, which has responsibility for policy and funding. Two members of the board are drawn from among the industrial associates and at least one each from the federal and provincial governments and the Board of Regents. Mr. Harold Snyder, the first director of C-CORE, has also retained a cross-appointment in the engineering faculty. He was recruited, along with his chief of administration, Mr. Grenville (secretary of the Royal Commission looking into the Ocean Ranger disaster), from a background in Newfoundland's largest engineering project at Churchill Falls.

The research program has evolved under the guidance of a committee appointed by the board, including key outsiders, called the Research Program Advisory Committee. This will no doubt evolve into a working-level evaluation and feedback device. Dr. Pallister was on the board and collaborated with C-CORE staff on the development not only of its research program, but in the assessments of ocean technology and related service industry that were prepared for NRC.

C-CORE has generated two small spin-off companies. The remote sensing group of about six investigators established itself as Remotec in 1978. Financial constraints at C-CORE may have initiated this spin-off prematurely and made it difficult for C-CORE to provide enough seed contracting to its spin-off. The other company, Instrumar, has had more of an incubator relationship with C-CORE. It was established in 1980 as a subsidiary of Memorial and C-CORE, and was subsequently purchased by its staff of nine over the following year.⁴⁵

A small number of students and faculty have become affiliated with projects at C-CORE, and the Ocean Engineering Information Centre (OEIC) is a joint project with the university. NRC and CISTI have contracted into OEIC to assist it in developing expanded information services related to a major NRC installation, AVMRI, discussed below.

The Newfoundland Oceans Research and Development Corporation (NORDCO)

NORDCO was established as a provincial Crown corporation in 1975, at the same time as C-CORE. Its mandate was designed to complement that of C-CORE: essentially to apply the results of research, particularly with respect to the marine service industry.

NORDCO is 86 per cent owned by the provincial government; its Crown corporation status makes it ineligible for federal research grants, but the incomplete provincial ownership permits it to bid on federal contracts. Most of its consulting work is carried out for industry. In the absence of substantial core funding from the province, such as the formal Provincial

Research Organizations receive, NORDCO has been building up its expertise through industrial contracting.

NORDCO is a sustaining Associate Member of C-CORE, but the line of demarcation remains fuzzy: C-CORE in theory takes engineering projects to the demonstration stage and then spins out the results, but in reality all members of the complex, including Remotec and the consulting associates and members of C-CORE, compete to a certain extent for the same contracts. The situation will be relieved when oil companies can be persuaded to locate some research as well as service facilities in St. John's. Industrial stimulation is indeed part of NORDCO's purpose, but it is operating without a major contracting budget and without control of either a regulatory instrument or a valuable package of technology. Indeed, the whole complex suffers from lack of development of intellectual property agreements.

There is a need for an AOSTRA-type of agency in the complex. This had been evident to Pallister and others at the Science Council of Canada, who called for the establishment of CoDevCo (see chapter 6, note 38) and more recently for a "Canadian Offshore Petroleum and Research Authority [COPTRA] ... to develop the ice technology needed for commercial production of Canadian offshore oil and gas."⁴⁶

Arctic Vessel and Marine Research Institute (AVMRI)

NRC seems finally to have a mandate to construct the "centre of excellence" called for in the ill-fated oceans policy of 1973. The central research facility is a pilot plant called the Arctic Vessel and Marine Research Institute (AVMRI), located adjacent to C-CORE on the Memorial campus. Much of the research group is still in Ottawa, and is part of the Marine Dynamics and Ship Laboratory at NRC. Although shipbuilding was once an important industry in Canada, there remain only a handful of naval architects, and fewer still with training in ice technology and the design of drilling rigs. NORDCO, through the provincial government, is under contract to find half the research staff for the new facility. The other half will be an expansion of the Ottawa group, which has already developed an extensive CAD/CAM facility in its ship

laboratory, as well as a capability for developing computer simulations based on data from its freshwater basins.

The AVMRI facility, with its 80 m ice model basin, will fill a gap in pilot plant and demonstration capability in the St. John's complex. The initial cost estimate was \$55.6 million. The tanks and support facilities will be made available to industry, university and government agencies on a cost recovery basis. An advisory committee of major participants will guide the development of the AVMRI program.

In the preliminary phase of construction, the serious issues of control of the technology have been deferred. Clearly, AVMRI as a pilot plant facility does not automatically, and perhaps cannot, function like an AOSTRA in this regard. Following the Science Council and Pallister recommendations for such an agency, the Sector Task Force on the Ocean Industry also reviewed the situation and called for a Canadian Ocean Technology Research Authority (COTRA), funded to a level of \$100 million over five years.⁴⁷ Aside from developing and controlling technology, COTRA would anticipate and encourage programs for the necessary scientists and engineers.

In summary, it can be observed that the St. John's complex is at an early stage of its development, and that the central institutions have suffered from the absence of an NRC Associate Committee to coordinate their physical development and bring to bear the power of actual institution-building agencies. A parallel problem in the evolving research program and technology production of the complex is now more critical. A technology development authority is needed now more than ever.⁴⁸

VII

FIVE EASY PIECES

We have argued in this paper that science and technology have become reunited as a system of knowledge, but that the institutions for the production, evaluation and transfer of knowledge have evolved separately for science and technology and to a large extent remain separate. Thus we are faced with the challenge of developing institutions within which current science/technology of relevance to industry can grow and flourish. Much of the tension associated with the institutional reintegration of science/technology at the level of research is experienced in the university, all the more so in Canada because private-sector industrial research is underdeveloped or in an early stage of development. The tension is heightened by the fact that science policy and expenditures are currently focused on the development of industrial technology, frequently in areas for which there is at present little or no research capacity in industry, and no pilot plant or development capability in universities.

Factors

As a result of these forces, and the fact that technology and expertise are now widely acknowledged as a significant factor in economic expansion and productivity growth, the challenge to current science policy in Canada is to build effective institutions for research and development on the university-industry frontier. Thus, beyond a preliminary analysis of linkage programs and barriers, our exploration has focused on the dimensions and range of institution-building in Canada, and in particular, on a university-based hybrid for pilot plant and demonstration activities that we have frequently referred to as a research factory in a selected area of generic technology.

Five factors or parameters of institutional development appear critical to the success of this activity.

Technology Assessment

Technology has to do with solutions to a particular and connected set of problems. Thus, institution-building in this area is not well served by policy outputs that merely announce a government or budgetary interest in some general area, such as an "oceans policy" or a strategic granting area like "energy" or "food." From the other point of view (the laissez-faire or "bottom-up" view of policy development) institutions that merely develop from the energy and initiative of individuals may be technologically misplaced and are almost certain to be underfunded and to remain for some time ineffective when they survive at all.

What is called for as a prerequisite to the development of effective research institutions is a careful analysis of current state-of-the-art science and technology with reference to a well-defined set of problems in a particular area of knowledge (or genre of science and technology), carried out with a view to locating gaps and opportunities. Such an analysis is an essential preliminary activity, and should not be confused with other uses of the term "technology assessment," which include reference to the political analysis of interests in a policy arena and the assessment of environmental or social effects of given technologies. Preliminary planning and information-gathering is critical because of the large investment and long-term commitment required in capitalizing a research factory type of facility.

The Research Factory

The research university, with its base in graduate education and research training in the arts and science faculties, evolved out of the institutional requirements of traditional scientific disciplines. Research in industrial science and technology also requires an institutional home, one that is often lacking at present. Between an idea and its full-scale industrial application is an essential process requiring pilot plant and demonstration facilities. This process is equivalent to the design of an experiment in traditional

science. It requires a factory for the production of knowledge relevant to a specific area of technology. The character of the work performed in a research factory is not less honourable because it is oriented to a specified utilitarian purpose. Rather utilitarianism becomes dishonourable when it is not informed by the higher values of civilization. This is a reason that it is desirable to locate research factories in the academic milieu.

Evaluation

Relevance is the key to the evaluation of research. Pilot plant and demonstration facilities are invariably expensive, and their operation must be kept relevant to the needs of industry. In traditional fields of knowledge, peer evaluation machinery is in place that attempts to ensure the relevance of new work to the progress of knowledge in a given field. Technology must also be relevant, but the evaluative institutions are different. Proposals for research in academic disciplines are evaluated by peer-review committees, and when the results are published, they are again the subject of peer evaluation. For this principle to work in areas of industrial science and technology, and particularly because of the cost of pilot plant demonstrations, the research program must be subjected to a detailed and ongoing technical evaluation by industrial peer investigators. A major reason for the existence of economies of scale in industrial research laboratories is the fact that proprietary information is under organizational control, and therefore conditions exist for limited peer evaluation. It is desirable to extend this beyond the confines of a single company. The barrier is that industrial researchers will normally work in conditions of relative confidentiality and have commitments to their organizations that may override commitments to the international science community. Evaluative techniques in this area are still very primitive and in need of further institutional development.

Control of Technology

Because scientific results are published, there is a widespread and mistaken illusion that this information is somehow free. However, information exchange in traditional science evolved in the form of a free circulation of authored results in return for recognition of prior discovery. This unwritten legisla-

tion has at least moderated the noisy and colourful history of priority disputes and the comparatively tame legal disputes surrounding patents. But publishing is somewhat peripheral to industrial technology, and patenting is just one of several techniques for protecting the type of intellectual property that results from projects in industrial laboratories, pilot plant facilities and university-based research factories.

Because of the proprietary and potentially valuable nature of industrial research; because of the cost of facilities and the necessity of bringing industrial partners in at every stage including evaluation; and, finally, because the work of one research factory will contribute to a larger area of technology involving the orchestration of other laboratories in industry and elsewhere - because of these factors, technology-specific policy is best implemented through some authority, such as AOSTRA, which has responsibility and funding for a well-defined major program and authority to control the technology that results from its activities. In effect, a "Technology Authority," unthinkable in traditional disciplines, appears most effectively to take the place of the benevolent and "disinterested" granting agency panels in traditional fields of science.

Coordination and Transfer of Technology

In implementing a major program of research, a technology authority can spread its risks by orchestrating a relatively large number of inexpensive university initiatives and a smaller number of pilot plant activities, and by negotiating with industrial partners for full-scale demonstrations. Coordination of a technology policy on this level is only possible if the technology authority or agency can control the technology and negotiate royalties and privileges at each stage of its development. Freedom must be preserved in such a system. This seems to be achieved when the technology authority acts as a catalyst for the expansion of a complex with many actors: the pilot plants have industrial partners and can pursue other courses and contracts; industrial partners have their own research programs, and many individual initiatives and spin-offs can be supported at the university level.

Paradoxically, it is because of the exercise of this sort of control that the circulation of proprietary information beyond the boundaries of the firm is possible. New devices are also required for the transfer of technology: they include technology evaluation meetings, special seminars, secondment of faculty, industrial supervision of graduate theses, and the development of patent searching and information services in specialized information centres.

Actors

We have isolated the factors critical to the development of effective university-industry linkages and observed that this amounts to a program of institution-building to provide unique research facilities and normative arrangements. In the cases discussed above, the energy and entrepreneurial spirit of particular institution-builders often proved crucial. A favourable host environment is also important: it involves the university attitude to technical expertise, and to its industrial clientele, and it involves the growing network of relations of the university with industry and government. In this context, the evolving set of policy instruments that we have discussed for the support of linkage activities may emerge from one of several sources:

University

Although the leverage available to individuals at the university appears to be limited with respect to linkage activities, nevertheless the attitude and climate of interaction that prevails on a campus is critical. A history of cooperative educational programs and active industrial contracting will give the university a valuable network of industrial contracts and expertise in dealing with patents, spin-off companies and licensing activity. This expertise is likely to be located in an evolved version of the Research Administration Office; frequently, its line of evolution is towards a range of services supported by a research park authority.

The dilemma for a traditional arts and science university is whether to try to open a window on industrial technology or to become involved in a large-scale research complex that will be largely beyond the control of the university. Industrial technology is either part of the problem or part of the

solution. With few exceptions, Canadian universities are looking at the problem rather than the solution.

Industry

Despite their private proprietary interests, firms also have some common interests: they benefit by recruiting from common sources of relevant expertise, for example; and they benefit from the development and transfer of generic science and technology that they are unable or unwilling to develop themselves on a proprietary basis, or that may have been initiated at the university and requires further industrial development. Thus, firms will become involved not only as contractors and associates of relevant research factories, but by being actively drawn into technical evaluations, exchanges or secondments, thesis supervision and specially negotiated technology consortia. Another program that has attracted industrial interest involves experiments with the off-campus curriculum, particularly graduate engineering programs that remain under university-based quality control but are located in particular industrial facilities. The industrial motivation may be similar to that which leads to endowment of a university chair, but the effect is much broader. Again, industry may often regard the university as a source for recruiting purposes, but as irrelevant with respect to new technology. The point is that while this may often be the case, it need not be, and the attitudes of potential actors and institution-builders are important.

Federal Government

Chapter 5 contains a survey of federal departments and agencies that have initiated linkage programs. Two difficulties exist. The difficulty of coordination is now being addressed by means of budgetary coordination and the re-emergence of NRC, which has a history of effective use of the Associate Committee as a prelude to institution-building through the co-opting of interests and the coordination of expertise. The second problem, the lack of specific programs in policy outputs, is a continuing difficulty of central agency operations that work from the top down through brief Cabinet documents and without adequate technology assessments or implementation strategies. The oceans policy was an illustration of this lack. (The Science Secretariat was

invented to overcome this problem, but it was quickly succeeded by the Science Council of Canada, which pursued a public interest course. MOSST, for its part, has shown little facility for drawing in the necessary expertise on particular issues.)

The current pre-eminence of NRC and the Economic Development Ministry is reminiscent of the productive institution-building years of the C.J. Mackenzie-C.D. Howe collaboration. The danger in this situation is that a number of expensive regional laboratories of NRC might be created, but without the ability to place themselves at the disposal of university and industrial partners. A base of expertise in science and technology is necessary, along with a measure of independence for the designated agency that must coordinate and co-opt individuals and activities from many conflicting jurisdictions. By contrast, line departments and agencies are generally structured around relations with a clientele of organizations and interests in some sector of the economy or society. For example, NSERC operates the peer-review system for traditional university departments and professional societies. This structure cannot serve the engineering community very well, nor that part of industry oriented towards university linkages. Clearly, actors at the federal government level are in a key position but there is historically a problem of federal actors proceeding alone, and bureaucratic organization militates against this sort of initiative.

Provincial Government

In recent years, provincial governments have become increasingly interested in science and technology policy as a part of regional economic development strategy, particularly in resource areas. Consequently, the Provincial Research Organizations are taking on corresponding significance as a source of expertise and a means of research policy implementation. Many of these have pilot plant capabilities and well-developed networks of industrial relations. Some of the PROs are located at or near universities and exercise many linkage functions. Provincial governments are also becoming more active in influencing the direction of specialization at some universities, because of declining enrolments. Provincial governments have experimented successfully with Crown

agency instruments, creating, for example, technology authorities, as well as PROs. A useful development would be the design of joint federal-provincial service agencies, perhaps in the form of pilot plant facilities, to serve the needs of specialized university research parks.

Research Factories

A fifth actor, or source of policy and influence in the university-industry scene, is the existing family of hybrid research institutions that are university based and have been set up to produce knowledge in particular areas of industrial technology. Many were established with limited five-year federal startup funds, or with limited foundation support. Other examples are regional laboratories of federal departments and agencies or Provincial Research Organizations. As such, they are likely to have a generalized or regulatory mandate, and often little incentive to actively pursue either industrial or university liaison. Although research factories may often be a catalyst in generating spin-off firms and university-industry linkages, they frequently lack the necessary core support and base of industrial associates to guarantee their survival on anything beyond a contract research basis.

Pieces of the Action

To summarize our findings, we have identified five factors that appear to have been essential in the institution-building activities examined in this study. Reference was then made to the sectoral sources of decision-making and influence on linkage activities. By way of conclusion, it may be useful to refer again to the five factors identified above, this time introducing some of the actors and associated activity that appear to have been particularly effective. The main text of chapter 5 contains detail on the whole range of particular policy instruments and programs exercised by these various actors. It has been observed, however, that given a positive university orientation to its industrial clientele, institution-builders can usually find a way to start up an operation regardless of the detail of the available programs. Here we are attempting to generalize upon the kinds of activity that have been found most effective.

The challenge of institution-building in this context might be considered equivalent in importance to creating the first generation of government and university laboratories. A veteran institution-builder on the American scene, Vannevar Bush, recounted some of his wartime experience, including the contracting of large-scale and targeted government laboratories directly into universities, in a book entitled Pieces of the Action (Morrow, New York, 1972). In the university-industry puzzle, pieces appear in fives.

Technology Assessment

The institution-builders mentioned in this study were apparently adept at putting together a network of individuals, often informally, who could serve to assess the state of knowledge in a particular area and identify gaps. NRC frequently used Associate Committees in this way. A problem with them is that appointments might often be too senior, and then the necessary expertise has to be assembled by means of a special conference or working group. Another problem can arise if the Associate Committee is also designed to co-opt various interests and to assist in the startup of an eventual institute. The same group may not be optimal for performing all three of these functions.

The essential preliminary activity is to assess all relevant science and technology in the problem area. There will be a temptation, in doing this, to mix in environmental assessments and to anticipate the social effects of particular technologies. Again, these are political functions, much too important to be left to a technical working group designed to assess the state-of-the-art in a certain area. These other kinds of technology assessment require higher-level political involvement and a broad base of public discussion and negotiation of interests. Such a political process may lead to the development of institutions designed for research related to regulatory activities. An important factor behind the "authority of knowledge" rationale for locating research factories in the academic milieu is precisely to bring the store of cultural values represented at the university to bear on the whole development of knowledge for practical ends. The point is, however, that these three notions of technology assessment are fundamentally unique and require different instruments for effective implementation.

Finally, the expansion of knowledge in all areas has made it virtually impossible for an individual institution-builder or his private network of informants to do an adequate job of technology assessment, considered in any sense, particularly where considerable public investment may be involved in the outcome. It is critical that preliminary technology assessments draw upon the best available expertise on an international basis. The cost for private networks may be high at later stages such as staffing an institution; but it could be prohibitive at the stage of doing technology assessments. New techniques should be explored for the purpose of identifying expertise in particular research areas.¹

The Research Factory

Once a needed program of research has been specified, the next requirement is a home. The construction of such a home, which we call a research factory, is the proper focus of the various interests to which the technology is relevant. The essential aspect of the research factory is its unique pilot plant and demonstration facilities, which will have been defined at least in general terms by the process of technology assessment. The industrial interests and the university should be invited to support the research factory through sustaining associate memberships. Firms should be able to contract proprietary work into it, and faculty and students should have access to its facilities. Line departments of government, including regulatory agencies, should be encouraged to contract work into the facility, or to locate related testing facilities in the same research complex.

Once government policy has been committed to the development of a particular complex of research facilities, the full powers of government procurement should favour that complex not only in research contracting, but in the purchase of products and services from its industrial associates and spin-off firms. The research complexes surrounding such universities as MIT and Stanford received a strong and sustained push from favoured government contracting, and indirectly, from hidden "pilot plant" facilities in the university, which, in the field of electronics, for example, are often an inherent part of up-to-date computer utilities and electronics laboratories.

In such special cases, which include Waterloo among others in Canada, the university may have accumulated sufficient facilities and other resources to act as the engine in a factory that generates an (unplanned) research complex about itself.

Evaluation

The work program of a research factory requires constant feedback and evaluation from current working-level investigators in industry. Industrial associate members can be invaluable in this regard, particularly if the intellectual property has been negotiated under a technology authority. The main devices used here are special seminars and congresses. Occasionally, the adequacy of the equipment, and less often, the research program itself should be subjected to a site visit by a kind of "accreditation committee" composed internationally of investigators who would have been capable of doing the initial technology assessment if the facility were being planned for the first time. A sunset strategy of this hue can bring sudden and unwanted changes. For this reason it has been particularly abhorrent to government laboratories, but at the same time, it can be the basis of renewal and relevance in real research factories.

Control of Technology

Probably the one most significant factor in the evolution of research factories in areas of industrial technology is the problem of controlling knowledge that is obviously not free and cannot be freely circulated. This kind of control appears to run counter to the academic ethos. But to become truly relevant to industrial requirements, research factories must generate proprietary information. With some difficulty, the factory may succeed in controlling within its associate membership at least that portion of the technology with which it is directly involved. However, this in turn is a limiting factor in its ability to interact effectively with other sources of technology.

A technology authority therefore presents itself as the centre piece of a functioning technology research complex. Making use of major contracting

funds, and if applicable, making full use of other licensing or regulatory powers at its disposal, the technology authority negotiates, in advance of funding, all rights and privileges associated with the technology produced. Obviously, AOSTRA is the model here; one hears, for example, of an "AOSTRA of the Oceans." One must observe that the controversial industrial initiatives described above with respect to the biology departments at MIT and at Massachusetts General Hospital amount to a "technology authority" that would be unwelcome at most Canadian universities. An effective federal-provincial technology authority in areas of shared jurisdiction is at present a challenge eluding Canadians.

Coordination and Transfer of Technology

The function of a technology authority is not merely to orchestrate activities among laboratories working in the same area of technology. In fact, it frequently happens in the development of industrial technology that the necessary pilot plant facilities and other projects are really of very different orders of magnitude. A lone professor, equipped with an idea he has tested on a piece of apparatus in his laboratory, whether or not he is also in receipt of a Senior Industrial Fellowship, is hardly in a position to negotiate wisely or successfully for a middle-range pilot worth perhaps several hundred thousand dollars, or for a full-scale demonstration with industrial partners in an industrial-scale facility worth several millions.

By controlling the technology, a technology authority can operate between these levels of scale, and can build the hybrid, university-based research factory that may be a necessary middle ground. If the technology itself is controlled, coordination and transfer are both possible and easy. It is a paradox that the old issues of academic freedoms should reappear in this way. But serious investigators in areas of industrial technology also require the protection that can be offered by a technology authority, one that can be held accountable and responsible. University administrations have traditionally accepted this responsibility with respect to academic scientists, and they might usefully experiment with the forms of technology authority evolving around them.

GLOSSARY

AOSTRA	Alberta Oil Sands Technology and Research Authority
ARC	Alberta Research Council
AUCC	Association of Universities and Colleges of Canada
AVMRI	Arctic Vessel and Marine Research Institute
BILD	Board of Industrial Leadership and Development
CAD/CAM	Computer-Assisted Design/Computer-Assisted Manufacturing
CAT	Centre of Advanced Technology
C-CORE	Centre for Cold Ocean Resources Engineering
CMG	Computer Modelling Group
CoDevCo	Canadian Ocean Development Corporation
CPDL	Canadian Patents and Development Limited
CRIQ	Centre de recherche industrielle du Québec
DRB	Defence Research Board
DREE	Department of Regional Economic Expansion
DRIE	Department of Regional Industrial Expansion
DSS	Department of Supply and Services
ERCB	Energy Resources Conservation Board
FCAC	Formation de chercheurs et action concertée
GREAT	Graduate Research in Engineering and Technology
GSC	Geological Survey of Canada
IDEA	Innovation Development for Employment Advancement
IIC	Industrial Innovation Centre
IMIC	Innovation Management Institute of Canada
INRS	l'Institut national de la recherche scientifique
IPB	Institute for Plant Biotechnology

IPDF	Industrial Postdoctoral Fellowship
IRA	Industrial Research Association
IRAP	Industrial Research Assistance Program
IREQ	Institut de recherche d'Hydro-Québec
IRF	Industrial Research Fellowship
IRI	Industrial Research Institute
IT&C	Department of Industry, Trade and Commerce
MAI	Management Advancement Institute
MIT	Massachusetts Institute of Technology
MOSST	Ministry of State for Science and Technology
MSERD	Ministry of State for Economic and Regional Development
NORDCO	Newfoundland Oceans Research and Development Corporation
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OEIC	Ocean Engineering Information Centre
ORF	Ontario Research Foundation
PAPRICAN	Pulp and Paper Research Institute of Canada
PCS	Potash Corporation of Saskatchewan
PILP	Program for Industry/Laboratory Projects
POS	Protein, Oil and Starch
PRAI	Project Research Applicable in Industry
PRL	Prairie Regional Laboratory
PRO	Provincial Research Organization
SCC	Science Council of Canada
SEDCO	Saskatchewan Economic Development Corporation
SRC	Saskatchewan Research Council
SUDIC	Sulphur Development Institute of Canada
TIS	Technical Information Service
TUNS	Technical University of Nova Scotia
VIDO	Veterinary Infectious Disease Organization
VLSI	Very Large Scale Implementation
WCVM	Western College of Veterinary Medicine

NOTES

I. Introduction

1. The notion of an institution is elaborated in chapter 3. In this study, by institution-building we refer to a process of construction - evolutionary or by design - that takes place at various levels: physical facilities, structural arrangements, legal-normative rules and the objectives and values involved in goal-seeking systems. In research institutions, developments at the legal-normative level - for example, peer evaluation within science - are critical.

2. The Science Council has in fact been active in this area of policy analysis: Innovation in a Cold Climate: The Dilemma of Canadian Manufacturing, SCC Report No. 15, Ottawa, 1971; The Weakest Link: A Technological Perspective on Canadian Industrial Underdevelopment, Background Study No. 43, Ottawa, 1978; Forging the Links: A Technology Policy for Canada, SCC Report No. 29, Ottawa, 1979; and Threshold Firms: Backing Canada's Winners, Background Study No. 48, Ottawa, 1982.

II. The Marriage of Science and Technology

1. F.M. Cornford, "Greek Natural Philosophy and Modern Science," in F.M. Cornford, The Unwritten Philosophy and Other Essays, Cambridge University Press, London, 1967, p. 93.

2. Eric A. Havelock, Preface to Plato, Harvard University Press, Cambridge, 1963, p. 208. Professor Havelock continues, "Refreshment of memory through written signs enabled a reader to dispense with most of that emotional identification by which alone the acoustic record was certain of recall. This could release psychic energy, for a review and rearrangement of what had now been written down, and of what could be seen as an object and not just heard and felt."

3. "She is not, I say, the maker of instruments for necessary purposes." Thomas Babington Macaulay, "Lord Bacon," Edinburgh Review, July, 1837, in Macaulay, Essays, Longmans, London, 1886, pp. 392, 393.

4. Rupert Hall, "The Scholar and the Craftsman in the Scientific Revolution," Marshal Claggett (ed.), Critical Problems in the History of Science, University of Wisconsin Press, Madison, 1959, pp. 16, 17.

5. Melvin Kranzberg, "The Unity of Science-Technology," American Scientist, March, 1967, vol. 55, no. 1, pp. 48-66; "The Disunity of Science-Technology," American Scientist, Spring, 1968, vol. 56, no. 1, pp. 21-31; and "The Spectrum of Science-Technology," Journal of the Scientific Laboratories, December, 1967, vol. 48, pp. 47-58. Several recent examples are discussed in D.C. Gazis, "Influence of Technology on Science: A Comment on Some Experiences at IBM Research," Research Policy, July, 1979, vol. 8, no. 3, pp. 244-259.

6. Abbot Payson Usher, A History of Mechanical Inventions, Boston Press, Boston, 1959, p. 84.

7. A. Wolf, A History of Science, Technology and Philosophy in the 18th Century, Vol. II, Harper's, New York, 1961, pp. 611-628.

8. D.S.L. Cardwell, Turning Points in Western Technology: A Study of Technology, Science and History, Watson Academic, New York, 1972, pp. 128-137. It is ironic that at the same time the Engine Reporter commenced publication, legislation came against the Luddite revolt, making destruction of the new power machinery a capital offence. See G.D.H. Cole, A.W. Filson, British Working Class Movements: Select Documents, 1789-1875, Macmillan, London, 1951, pp. 111-115.

III. The Institutional Development of Science and Technology

1. Hastings Rashdall, The Universities of Europe in the Middle Ages; 3 vols., Oxford, 1936; Gabriel Compayré, Abélard and the Origin and Early History of Universities, Heineman, London, 1893.

2. Robert Hooke, "The Business and Design of the Royal Society," quoted in Everett Mendelsohn, "The Social Construction of Scientific Knowledge," E. Mendelsohn, P. Weingart, R. Whitley (eds.); The Social Production of Scientific Knowledge, Reidel, Dordrecht, 1977, p. 18.

3. Ten per cent of papers in the first two years of the Philosophical Transactions were in technology; the share reached as high as 20 per cent by 1675 but drifted off to 4 per cent by the end of the century. Many members were drawn from manufacturing circles. Robert K. Merton, "Changing Foci of Interests in the Sciences and Technology," The Sociology of Science: Theoretical and Empirical Investigations, University of Chicago Press, Chicago, 1973, p. 197. For a current look at this area of research, see R.G. Frank, "Institutional Structure and Scientific Activity in the Early Royal Society," XIVth International Congress of the History of Science, No. 4 (1975), pp. 82-101; and the exchange in Social Studies of Science, Vol. 11, 1981, pp. 327-364, and Vol. 12, 1982, pp. 451-466.

4. A.W. Renton, T.A. Ingram, "Patents," The Encyclopedia Britannica, Vol. 11, 11th ed., Cambridge University Press, Cambridge, 1910, pp. 903-910. Ironically, the literature on patents has become vast: still a good reference

is H.G. Fox, Monopolies and Patents, University of Toronto Press, Toronto, 1947.

5. D.S.L. Cardwell, "The Professional Society," in Norman Kaplan, ed., Science and Society, McNally, Chicago, 1965, p. 92; and Joseph Ben-David, A. Zloczower, "Universities and Academic Systems in Modern Societies," in *ibid.*, pp. 62-85. On similar developments in the United States, see Arnold Thackray, University-Industry Connections and Chemical Research: An Historical Perspective, Report to the National Science Board, Washington, 1982.

6. Katherine Stone, "The Origins of Job Structures in the Steel Industry," Conference on Labour Market Stratification, Harvard, 1973, in Review of Radical Political Economy, Summer, 1974; also Edwin Layton, The Revolt of the Engineers: Social Responsibility and the American Engineering Profession, Press of Case Western Reserve, Cleveland, 1971, and Robert Perrucci, Joel Gerstl, Profession Without Community: Engineers in American Society, Random House, New York, 1969.

IV. The Evolving Research Infrastructure in Canada

1. On the centre-periphery model, see Edward Shils, "Centre and Periphery," in The Logic of Personal Knowledge: Essays Presented to Michael Polanyi on his Seventieth Birthday, Free Press, Glencoe, 1964; Christopher Vanderpool, "Center and Periphery in Science" and George Basalla, "The Spread of Western Science" in Sol Restivo, C. Vanderpool (eds.), Comparative Studies in Science and Society, Merrill, Columbus, 1974.

2. Andrew White, "Scientific and Industrial Education in the United States," Popular Science Monthly, June 1874, vol. V, reprinted in Carroll Pursell (ed.), Readings in Technology and American Life, Oxford University Press, New York, 1969, p. 180.

3. Arthur D. Little, "Industrial Research in America," Science, 7 November 1913, in *ibid.*, p. 315.

4. Morris Zaslow, Reading the Rocks: The Story of the Geological Survey of Canada, Macmillan, Toronto, 1975.

5. The acknowledgement of this came at the industrial exhibitions, the first of which was held at the Crystal Palace in London, 1851; *ibid.*, pp. 55-61. For an account of the interests of the Natural History Society of Montréal, the Canada Land Company in Upper Canada, and a rich coterie of political actors in the founding of the Survey, see Suzanna Zeller, "Origins of the Geological Survey of Canada," unpublished ms., University of Toronto, 1983.

6. William Logan to Sir Henry de la Beche (April, 1843), quoted in T.H. Levere, R.A. Jarrell (eds.), A Curious Field Book: Science and Society in Canadian History, Oxford Press, Toronto, 1974, p. 53.

7. Stanley Frost, McGill University: For the Advancement of Learning, vol. 1, McGill-Queen's University Press, Montréal, 1980.

8. Robin Harris, A History of Higher Education in Canada: 1663-1960, University of Toronto Press, Toronto, 1976.

9. Proceedings, Royal Society of Canada, ser. 2, vol. 8, May 1902. G.M. Dawson had virtually failed to mention the universities at all in his 1894 presidential address, "The Progress and Trends of Scientific Investigations in Canada." See also W.P. Thompson, Graduate Education in the Sciences in Canadian Universities, University of Toronto Press, Toronto, 1963, p. 30, for a note on the adoption of the American graduate school model.

10. A brief account of the empire conferences, in response to which Canadians formed the initial version of the Association of Universities and Colleges of Canada in 1911, can be found in Harris, op. cit., pp. 205, 206; on the NRC as a response to imperial designs see Wilfrid Eggleston, National Research in Canada: The NRC, 1916-1966, Clarke, Irwin, Toronto, 1978, pp. 2,3; and Mel Thistle, The Inner Ring: The Early History of the National Research Council of Canada, University of Toronto Press, Toronto, 1966, pp. 6,7.

11. Philip Enros, "The University of Toronto and Industrial Research in the Early Twentieth Century," unpublished ms., University of Toronto, 1983, p. 6; and Edward Stewart, "The Role of the Provincial Government in the Development of the Universities of Ontario 1791-1964," doctoral dissertation, University of Toronto, 1970, pp. 267-269.

12. E.A. Corbett, Henry Marshall Tory, Beloved Canadian, Ryerson Press, Toronto, 1954, p. 131. See also Maureen Riddell, Research Council of Alberta: An Historical Review, University Archives, University of Alberta, May, 1977.

13. Mario Creet, "H.M. Tory and the Secularization of Canadian Universities," Queen's Quarterly, Winter, 1981, vol. 88, no. 4, p. 725; and the confidential letter from Tory to Premier Rutherford of Alberta, reprinted in Corbett, op. cit., pp. 87, 88.

14. Socioeconomic conditions in Québec, combined with a classical French-Catholic educational system that relegated the teaching of science and technology to an inferior position, made the creation of École polytechnique in 1873 somewhat premature. By 1920, École had graduated only 75 students. They were to some extent in competition with McGill not only for industrial support, but for students as well. Some 113 engineering students came out of McGill in 1914 alone. The research tradition finally became established at École after WW II. Jean-Marie Desroches et Robert Gagnon, "Georges Welter et l'Émergence de la Recherche à l'École polytechnique de Montréal, 1939-1970," Recherches Sociographiques, 1983, vol. 24, no. 1, pp. 33-54.

15. Arthur Cordell, James Gilmour, The Role of Government Laboratories and the Transfer of Technology to the Manufacturing Sector, Science Council of Canada, Background Study No. 35, Supply and Services Canada, Ottawa, 1976, especially chapter IV, sec. 6.

16. Graham Spry, "The Canadian Broadcasting Corporation 1936-1961," Canadian Communications, Autumn, 1961, vol. 2, no. 1, p. 15; also, Alvin Finkel, Business and Social Reform in the Thirties, Lorimer, Toronto, 1979.

17. H.M. Tory to Sir Arthur Currie (7 February 1928): "... I am now backing the development of a Research Institute which will deal primarily with industrial problems," in Thistle, op. cit., p. 294. Despite his experience in Edmonton with the Industrial Laboratory, he did not immediately see the value of a university location for these facilities. His later experience with the Grain Research Committee and the Prairie Regional Laboratory reversed this impression (see the Saskatchewan case study below).

18. Despite this, the original planning of ORF organized the research program around the concept of aid to industrial research associations. By the late 1930s, ORF had given up on this idea and organized itself as a contract research organization for individual firms.

V. Policy Instruments

1. Department of Finance Data, House of Commons, Special Committee, The Federal-Provincial Fiscal Arrangements, Queen's Printer, Ottawa, 1981, Chapter III.

2. For details of the field of federal-provincial negotiating machinery, see Richard Simeon (ed.), Confrontation and Collaboration: Intergovernmental Relations in Canada Today, Institute of Public Administration, Toronto, 1979.

3. The structure, as reorganized in 1982, can be summarized as follows. The Cabinet Committee for Economic and Regional Development is served by a central Ministry of State for Economic and Regional Development (MSERD), which controls the \$6.8 billion economic development envelope, the \$2.6 billion energy envelope and a new regional fund to assist in establishing the regional or decentralized character of development plans. The regional fund is to reach \$200 million by 1984-85. The economic development envelope contains, in addition to and in a sense reporting to MSERD: agriculture, communications, consumer and corporate affairs, much of energy, mines and resources, environment, fisheries and oceans, labour, transport, science and technology, and a new Department of Regional Industrial Expansion (DRIE). The trade functions of the old ministry (IT&C) are with External Affairs, while DRIE retains the rest (including many programs for university-industry linkage). The programs of NRC are thus considered in the same envelope (under MOSST) as those of NSERC, the Natural Sciences and Engineering Research Council. These developments were critical for the recent major institution-building programs of NRC.

4. H.M. Tory, 1926, quoted in Eggleston, op. cit., p. 26.
5. Eggleston, op. cit., p. 27.
6. NRC, Activities of Associate Committees, 1982-83, Ottawa, 1982.
7. The major commissions looking at this area in the late 1960s saw a conflict between granting functions for basic university research and the support of national laboratories. The Macdonald Committee and the Senate Special Committee concurred in this finding. However, they failed to anticipate the problems that a separation of functions would pose for institution-building activities. For its part, the Science Council recommended an interim period in which three separate parliamentary votes of funds would continue to support the laboratories, university research and industrial programs, but in which the period of institution-building under the NRC programs of negotiated development and strategic grants could go forward. Science Council of Canada, University Research and the Federal Government, Report No. 5, Supply and Services Canada, Ottawa, 1969. At present, coordination relies on a formal arrangement between the presidents of NRC and NSERC. A position has been created at NRC to look into the university scene.
8. J.B. Brebner, Scholarship for Canada, quoted in W.P. Thompson, Graduate Education in the Sciences in Canadian Universities, University of Toronto Press, Toronto, 1963, p. 16.
9. Science Council of Canada, University Research and the Federal Government, Report No. 5, Supply and Services Canada, Ottawa, 1969, p. 11.
10. NSERC, A Five-Year Plan for the Programs of the Natural Sciences and Engineering Research Council, Ottawa, 1979, p. 45.
11. NSERC, Report of the President, 1982-83, Ottawa, 1983, p. 35.
12. NSERC's progenitor, the NRC, frequently experienced pressures from the engineering community to create an Engineering Research Council that would distribute research grants. The NRC dealt with this by establishing, for example, an Advisory Committee on Applied and Engineering Research in 1966, which helped defuse the situation. Minutes of the First Meeting, Advisory Committee on Applied and Engineering Research, Aug. 25, 1966, NRC Archives.
13. Sidney I. Featherman, "An Examination of Programs for Technology Transfer: Industrial Research Institutes and Centres of Advanced Technology," Internal document, Department of Industry, Trade and Commerce, January 1980.
14. In a summary of its first decade, I.R. McGill reported \$19.7 million in contracts, 44 per cent generated in the engineering faculty. I.R. McGill, The First Decade, 1971-1981, Montréal, 1981.
15. Sidney I. Featherman, op. cit. It has recently been argued that Canadian universities add a ridiculously low percentage (on average about 30 per cent) to their direct costs to cover overhead. James A. McPherson, "How

Universities Sell Themselves Short," Canadian Research, October 1983, vol. 16, no. 6, pp. 27-29.

16. Nevertheless, long-term and sufficient funding, even in the case of the PROs, has been a critical element in their success. See Donald J. Le Roy and Paul Dufour, Partners in Industrial Strategy: The Special Role of the Provincial Research Organizations, Science Council of Canada, Background Study 51, Supply and Services Canada, Ottawa, 1983, pp. 66-67.

17. NSERC, Report of the Task Force on Research Equipment, Ottawa, 1981.

18. "Microelectronics Research," Canadian Research, February 1982.

19. "Draft Agreement for the Microelectronics Development and Applications Centres Inc.," Department of Regional Industrial Expansion (DRIE), Ottawa.

20. Canada Commerce, Department of Industry, Trade and Commerce, October 1981.

21. Research Triangle Institute, An Analysis of the National Science Foundation's Innovation Centres Experiment, NSF, Washington, 1977.

22. A detailed description of the workings of the Inventors' Assistance Program is given by Margaret Hutchison, "Encouraging Canada's Inventors," Canadian Research, May 1978, vol. 11, no. 3, pp. 30-32.

23. Innovation Management Institute of Canada, "Innovation Centres: What They Are and What They Aren't," IMIC Information, June 1978, vol. 5, no. 1, pp. 12-14.

24. The Centre holds an equity position of 25-60 per cent in six of these firms, and collects royalties from four others. Centre d'innovation industrielle, Deuxième Rapport Annuel, Montréal, 1982.

25. Treasury Board, Policy and Guidelines on Contracting-Out in Science and Technology, Ottawa, 1977, p. 6. For a recent discussion, see A.B. Supapol, D.B. McPetridge, An Analysis of the Federal Make-or-Buy Policy, Economic Council of Canada, Ottawa, 1982.

26. The case for the Provincial Research Organizations' participation in the Contracting-Out policy is made in Le Roy and Dufour, op. cit., p. 56.

27. When we come to describe the functioning of this special class of research institutions, the portmanteau research factory is employed in order to refer not just to unique pilot plant facilities, but also to the normative innovations that are required of a university-based institution accountable in the industrial market place.

28. On IREQ-university collaboration, see Institut de recherche d'Hydro-Québec, Report of Activities, 1981, pp. 203-205. On INRS, see

Maier Blostein, "INRS-Telecommunications: An Overview," Telesis, 1982, vol. 9, no. 1, pp. 2-3.

29. W.H. Gauvin, "Actions Concertées - A Powerful Tool for Successful R&D," Chemistry in Canada, February 1979, vol. 31, no. 2, pp. 15-19; see also Maier Blostein, "A New Industry-University Interface," Telesis, October 1977, pp. 138-141.

30. An interesting recent development on this concept is described in Justin Bloom, Shinsuke Asano, "Tsukuba Science City: Japan Tries Planned Innovation," Science, June 1981, vol. 212, pp. 1239-1247.

31. A total of 54 awards were made and 38 renewed in 1982-83, worth \$1,058,000. Science Council of British Columbia, Fifth Annual Report, 1982-83, Victoria, 1983.

32. One of the better collections in this genre is W.T. Stanbury (ed.), Government Regulation: Scope, Growth, Process, Institute for Research on Public Policy, Montréal, 1980.

33. The argument on this point is in Chapter 3. Much of the development took place within military institutions and private concerns associated with canal and railway building. The impulse to institutionalize this knowledge was not encouraged at universities. Two years after Confederation, with the paltry university offerings that had been made available either withdrawn or dying of neglect, Hastings County set aside funds to endow a chair of mining and agriculture at Albert College in Belleville. Robin Harris, A History of Higher Education in Canada, 1663-1960, University of Toronto Press, Toronto, 1976, p. 165.

34. Of the 15,000 students in co-op programs, 7,000 were in science and engineering courses. Canadian Association for Cooperative Education, 1982-83 Directory.

35. C.A. Sankey, PAPRICAN: The First Fifty Years, Pulp and Paper Research Institute of Canada, Montréal, 1976.

36. Norman F. Eaton, "Development and Transfer of Multi-Discipline Technologies," Canadian Research, May 1977, p. 15. See also "A Collaborative Interface for Industrial Technology Development," in Challenge of the Research Complex, Science Council of Canada, vol. 2, Proceedings P 81/5, Ottawa, 1981, p. 177.

37. Francis Narin, "Assessment of Technological Performance Utilizing Patents and Patent Citations," Computer Horizons, Cherry Hill, 1983; and Mark Carpenter, F. Narin, "Assessment of the Linkages Between Patents and Fundamental Research," OECD, Paris, 1982.

38. David Dickson, "MIT Agrees to Accept Whitehead Grant: Faculty Votes Yes but Strings Remain," Nature, November 28, 1981, vol. 294, p. 297. This is one of several industrial incursions of this sort. The German firm Hoechst,

one of the world's largest chemical firms, recently created an entire department for molecular biology at Massachusetts General Hospital, in part because the constraints on German universities are too severe. Dickson, "German Firms Move into Biotechnology: The Academic Industrial Complex," Science, December 24, 1982, vol. 218, p. 1287.

39. IBM-Waterloo announcement, University Affairs, March 10, 1983, vol. 24, no. 3.

40. Nordicity Group Ltd., J.A. McPherson et al, Sheridan Research Management Corporation: Feasibility and Planning Studies, August 1979; Interim Report, April 1980.

VI. The Technology Research Complex: Selected Cases

1. Kevin H. Burley (ed.), The Development of Canada's Staples, 1867-1939: A Documentary Collection, Carleton Library, McClelland and Stewart, Toronto, 1970, Part 1, "The Wheat Economy." Also Vernon Fowke, Canadian Agricultural Policy: The Historical Pattern, University of Toronto Press, Toronto, 1946, chap. 9. Ottawa did not, of course, invent the idea of experimental farms. The elder Saunders, who put the federal system together, was influenced most by the recent American experience, though Canadian variations stretched back to the work of Bishop Laval in 1670. [J.C. Chapais, "Notes historiques sur les écoles d'agriculture dans Québec," Montréal, 1916, quoted in Fowke, *ibid.*, p. 226.] The two great demands of western agrarian politics at that time were reciprocity in US trade and control of the wheat trade. Both of these demands were turned down by the Borden government; part of the compensation was the Agricultural Instruction Act of 1913 which provided for \$10 million to the provinces over an initial ten-year period.

2. To complete the narrative, the committee subsequently differentiated into five associate committees: Grain Research, Plant Disease, Plant Breeding, Animal Nutrition and Fats and Oils. Research grants for the first four were placed under a Prairie Regional Committee during the war, and eventually they were transferred to the Department of Agriculture in 1969. The operation was largely financed in the Depression through the sale of "overages," or excess grain in public elevators.

3. Continuing funds came from DRB and NRC, and the name was changed to the Institute of Space and Atmospheric Studies in 1966, when they took on the development of control instrumentation for rockets.

4. The Electronics Communicator, September 8, 1982, vol. 13, no. 31. The notion of a chosen instrument is favourably described in John Shepherd, "Hidden Crown Corporations: The Private Corporation as a Chosen Instrument," Policy Options, May 1981, vol. 2, no. 2, p. 40.

5. C.J. Mackenzie, The Mackenzie-McNaughton Wartime Letters, ed. M. Thistle, University of Toronto Press, Toronto, 1975, p. 129.

6. Recommendation of the Prairie Regional Committee, November 3, 1943, quoted in N.T. Gridgeman, Biological Sciences at the National Research Council of Canada: The Early Years to 1952, Wilfrid Laurier University Press, Waterloo, 1979, pp. 71, 72. Wilfrid Eggleston, National Research in Canada: The NRC 1916-1966, Clarke Irwin, Toronto, 1978, p. 322, provides an interesting account of these events based on Mackenzie's daily journals.

7. This may now be changed, with the renaming of the Institute to reflect NRC's proposed program development in biotechnology, and a \$6 million increase in its budget.

8. Food Protein Study Group, Food Proteins from Grains and Oilseeds: A Development Study Projected to 1980, Ottawa, 1972. It is interesting that this same need for pilot plant facilities had been observed by the Prairie Regional Committee in 1943, and recommended for IPB (chapter 6, note 6).

9. The food research facility at TUNS is not only unique in seafood and oils research, it has a unique history as well. It was more or less salvaged singlehandedly by its director, Graham Bligh, after having been set adrift by the federal government.

10. John Richards, Larry Pratt, Prairie Capitalism: Power and Influence in the New West, McClelland and Stewart, Toronto, 1979, chaps. 5, 6. SRC was first established in 1930, but was forced into an early retirement in 1932 by the Depression.

11. Frances Anderson, Olga Berseneff-Ferry and Paul Dufour, "Le Développement des Conseils de Recherche Provinciaux: Quelques Problématiques Historiographiques," HSTC Bulletin, January 1983, vol. VII, no. 1, p. 36.

12. J. Richards, L. Pratt, op. cit., chap. 10, "Potash, Populists and Fabians," p. 250.

13. Sec. 109 appears to make the provision that resources belong to the Crown in right of the provinces, while Sec. 91, Part 3 appears to give the federal government extensive indirect taxing powers over the resources, although direct taxes on Crown assets are excluded in Sec. 125. The subsequent court decisions have generally supported federal claims in these disputes.

14. Northern Telecom had just negotiated a provincial contract with Saskatchewan's Telecommunications Corporation worth \$22 million. It must be noted that the competition for locating facilities in one province or another may often be a purely zero-sum game and hence self-defeating in the long run.

15. Mr. Bennett also came out of the political wilderness to form a federal government in 1930, rejoining the old struggle with Tory at the NRC: minute details of travel expenses had to be defended; questionable scholarship candidates were pushed on an unwilling Council; the furnishings in Dr. Tory's office became a subject of public dispute, the waste basket alone occupying the wit of the House of Commons during several question hours. Selected correspondence in Mel Thistle, The McKenzie-McNaughton Wartime Letters,

University of Toronto Press, Toronto, 1975, pp. 361-385. An account of the early years of the University of Alberta is in E.A. Corbett, Henry Marshall Tory, Beloved Canadian, Ryerson Press, Toronto, 1954, chaps. 11, 12.

16. Alberta Research Council, Long Range Plan, Edmonton, 1979. Historical developments are surveyed in Maureen Riddell, Research Council of Alberta: An Historical Review, University of Alberta, Edmonton, 1977.

17. An example is the hot water separation process used in the Great Canadian Oil Sands Limited plant at Athabasca in 1967. The Oil Sands Research Centre of ARC is today the major instrument of AOSTRA middle-scale pilot projects.

18. The size of this and subsequent oil wells before 1936 was small. Natural gas was produced in the Turner Valley from 1914.

19. M. Zaslow, Reading the Rocks, pp. 294-296, 348. This symbiotic relationship was critical, since major strikes did not occur in the Turner Valley until 1936; Leduc came in in 1947 and the elephant at Pembina near Edmonton in 1953. Exploration resembles research in the sense that, in recovering information from nature, most investigators are drilling dry holes most of the time, and returning with limited gushers some of the time. Elephant hunting, though rarely successful, has long been understood in polite circles to be unfair to elephants. The Survey never exacted fees or concessions from Imperial for handing them the Turner Valley field.

20. E.J. Hanson, Dynamic Decade, Toronto, 1958, quoted in Larry Pratt, "The State and Province-Building: Alberta's Development Strategy," ed. Leo Panitch, The Canadian State: Political Economy and Political Power, University of Toronto Press, Toronto, 1977, p. 136. In one sense, Imperial's control of gas markets in Calgary encouraged the independents to flare the gas for which they had no market.

21. In this respect, Dr. Newton likened Alberta gas to hydro-electric power in the St. Lawrence Valley (Pratt, op. cit., p. 140). As in the east, the mythic powers of this elixir were not overlooked: "... gas kept the street lights on and the barn warm and the house cheerful. The vast caverns of natural gas beneath the farm or the thousands of cubic feet running by in a pipe was part of the everyday life and folklore of Alberta. God had put it there for the enjoyment of His people. Woe betide the politician who sold such a birthright." (Kilbourn, Pipeline, quoted in Pratt, op. cit., p. 140.)

22. The value of the Fund exceeded \$10 billion in 1982.

23. C.W. Bowman, "The Alberta Oil Sands Technology and Research Authority," Challenge of the Research Complex, vol. 2, Proceedings, Science Council of Canada, Ottawa, 1981, p. 147.

24. Only about 5 per cent of the oil sands resource can be recovered by current technology for surface mining. In situ technology must therefore be developed for separating bitumen from the tar and oil sands that cannot be

mined initially. These joint ventures thus involve major-scale pilots operated by companies on their own leases and applying their best technology.

25. The chairs in effect place senior investigators in oil sands research in contact with students in Alberta universities, with 75 per cent of their time free for research. In addition to fellowships, AOSTRA supports 75 per cent of the industrial salary of Master's students attending a co-op program in oil sands engineering at the University of Alberta, including 16 months of approved field research.

26. The major projects are the in situ oil sands ventures with Shell at Peace River (both shares - \$100 million by 1981), Amoco, - \$45 million, and B.P. at Cold Lake - \$18 million. Annual Report, AOSTRA, Edmonton, 1981, pp. 36, 37.

27. AOSTRA has also recently initiated an Inventors Grant Assistance Program, which will provide seed money (\$5,000 to \$50,000) to develop inventions to a commercial stage.

28. Randy Scotland, "Petro-Canada Research Centre: Helping to Move Canada to Oil Self-Sufficiency," Canadian Research, April 1980, p. 36. The fascinating story of Petro-Canada itself is outside the scope of this study, though clearly, its establishment by the minority federal administration in 1975 was critical to many of the developments in this case study. Its first big acquisition was Atlantic Richfield, which had recently caused so much difficulty in the Syncrude negotiations.

29. The research program was described to a joint Chemical Institute of Canada, Canadian Society of Chemical Engineers Symposium, "Petroleum Process Research and the R&D Facility," May 5, 1981.

30. Established in 1954 by the Social Credit Government, officially not as a Crown agency, but an industrial consortium friendly to the government.

31. Such an AOSTRA-like biotechnology authority was proposed in 1981 by the University of Calgary. "Alta-Biotech: A Proposal for an Alberta Biotechnology Research Organization," prepared by the University of Calgary Biotechnology Study Group, June 1981.

32. Theodore Layng, "Early Geographical Concepts of the Northwest Passage," North, July 1966, vol. 13, no. 4.

33. Scientists of the environmental persuasion became concerned when the US, after making large oil discoveries at Prudhoe Bay in 1968, embarked on a pilot project of sailing the oil tanker "Manhattan" through the Passage in both directions the following year. One example of this concern is Ian McTaggart Cowan, "The Ecology of the North: Knowledge is the Key to Sane Development," Science Forum, February 1969, no. 7, p. 3. The very extensive Polar Continental Shelf Project, which has been fundamental to resource development in the Arctic, was created partially in response to American activities on the DEW Line in the fifties.

34. A.P. Low, GSC Annual Report, 1895, no. 8; GSC Field Notebook 2450; M. Zaslow, op. cit., pp. 168-170; F.J. Alcock, "Albert Peter Low," The Canadian Geographical Journal, April 1954, vol. 48, no. 4, p. 160.

35. Kenneth Rea gives a brief account of the iron ore development in K.J. Rea, The Political Economy of Northern Development, Study 36, Science Council of Canada, Supply and Services Canada, Ottawa, 1976, p. 58.

36. Philip Smith, Brinco: The Story of Churchill Falls, McClelland and Stewart, Toronto, 1975, p. 62.

37. The inquiry has been regularly reported in Oil Week, Oct. 25, 1982 - April 11, 1983.

38. The suggested name was CoDevCo, the Canadian Ocean Development Corporation, Science Council of Canada, Canada, Science and the Oceans, Report #10, Supply and Services Canada, Ottawa, 1970.

39. Ministry of State for Science and Technology, Statement on Ocean Policy, Ottawa, July, 1973.

40. Three Mobil contracts in 1981-82 totalled \$392,274, and two grants from Shell amounted to \$134,000 (Memorial Gazette, April 21, 1983, p.4).

41. Pallister Resource Management, Steering a Course to Excellence: A Study of the Canadian Off-Shore Oil and Gas Service Industries, NRC, Ottawa, 1977; Research and Development for Ocean Engineering in Cold Regions, NRC, Ottawa, 1978. The Science Council also attempted, in Background Study #30, an assessment of this technology: M. Gibbons, R. Voyer, A Technology Assessment System: A Case Study of East Coast Offshore Petroleum Exploration, SCC, Supply and Services Canada, Ottawa, 1974.

42. Dr. Pallister was vice-chairman of the Council until May 1975, and had served on its Committee on Marine Science and Technology (Background Study #16, 1971, and Report #10, 1970, which recommended CoDevCo). His last three years on the Council coincided with Dr. Bruneau's first term of membership. The Science Council meeting in Calgary was in June 1974, and included a side trip to the Athabasca oil sands.

43. A.A. Bruneau, "Using All Our Resources: Some Comments on Research Collaboration amongst Universities, Governments and Industry," in Challenge of the Research Complex, Proceedings, Vol. 2, Science Council of Canada, Ottawa, 1981, pp. 213, 214.

44. C-CORE, Constitution and By-Laws, Revised 1980, Article 4.

45. H.L. Snyder, D.M. Grenville, "Engineering Research in a Cold Ocean Environment," C-CORE, 81-15, The Canadian Research Management Association Annual Meeting, Halifax, 1981, p. 7.

46. Pallister Resource Management, op. cit., 1978, p. 40. On the provincial side, Dr. William Russell, Director of Engineering Systems in the Petroleum Directorate, which also licenses rigs, recently suggested building up a heritage type of fund of \$10 million/yr based on a levy of drilling permits, to be used for generating necessary technology after the manner of AOSTRA (Proceedings of a Seminar on Science Policy for Newfoundland and Labrador, Department of Development, ed. Rex Gibbons, Paul Maher, St. John's, 1982, p. 45).

47. Consultative Task Force, Report on the Ocean Industry, Department of Industry, Trade and Commerce, Ottawa, 1978, p. 13. Pallister and Bruneau were members, along with then president of NORDCO, J. Furst.

48. Dr. Pallister and Dean Adams at Alberta have recently proposed another individual initiative, C-FER, a Devonian Centre for Frontier Engineering Research, which will use data from C-CORE (or possibly AVMRI) to work on steel structures. In the absence of a Technology Authority, the St. John's complex threatens to spill all over the country without itself reaching a critical size.

VII. Five Easy Pieces

1. The author described an effective technique in an unpublished Science Council manuscript ("Research in Canada: An Information Theoretic Investigation"). See James MacAulay, "A Family of Research Indicators Derived from a Bibliometric Analysis," OECD, Proceedings, Workshop on Science Indicators, Paris, September 1980; "The World Brain Again: This Time with Feeling," Joint Meeting, Classification Society, Psychometric Society, Proceedings, Montréal, May 1982; and An Indicator of Excellence in Canadian Science, Statistics Canada, Ottawa, 1984.